PB82-237330

Environmental Monitoring at Love Canal: Volume I

(U.S.) Environmental Protection Agency
Washington, DC

May 82

U.S. Department of Commerce
National Technical Information Service
NTIS

United States
Environmental Protection
Agency

EPA-600/4-82-030a
May 1982

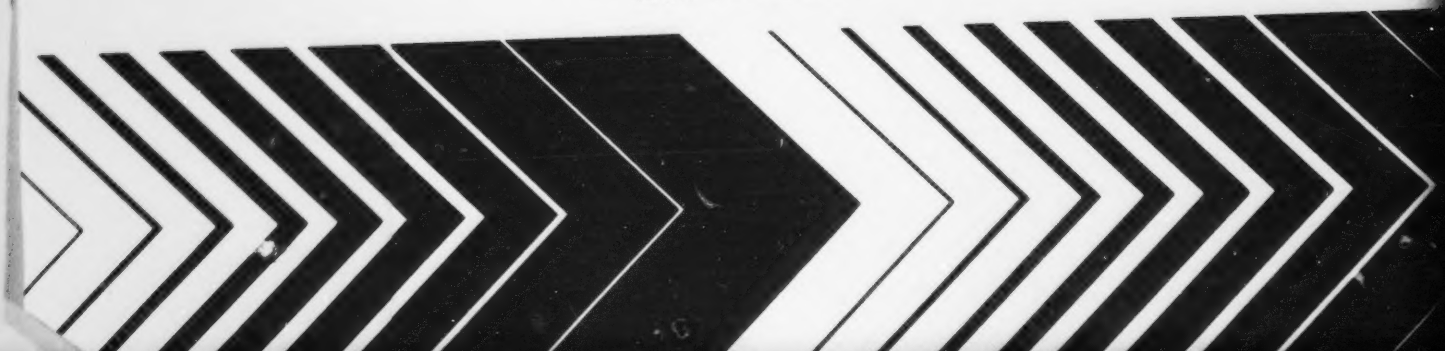
Research and Development

PB82-237330

EPA

Environmental Monitoring at Love Canal Volume I

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE



TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-82-030a	2.	3. RECIPIENT'S ACCESSION NO. PB82-237330
4. TITLE AND SUBTITLE ENVIRONMENTAL MONITORING AT LOVE CANAL. Volume I.		5. REPORT DATE May 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Office of Monitoring Systems & Quality Assurance Office of Research and Development U.S. Environmental Protection Agency Washington, DC 20460		13. TYPE OF REPORT AND PERIOD COVERED In-House
		14. SPONSORING AGENCY CODE EPA/600/00

15. SUPPLEMENTARY NOTES

16. ABSTRACT

During the summer and fall of 1980 the U.S. Environmental Protection Agency (EPA) conducted a comprehensive multimedia environmental monitoring program in the vicinity of the inactive hazardous wastes landfill known as Love Canal, located in Niagara Falls, New York. As a result of a presidential state of emergency order issued on May 21, 1980, EPA was instructed to assess the extent and degree of environmental contamination that was directly attributable to the migration of substances from Love Canal into the occupied, residential area around the former canal defined by: Bergholtz Creek on the north; 102nd Street on the east and 103rd Street on the southeast; Buffalo Avenue on the south; and 93rd Street on the west. The area closest to the former canal, currently owned by the State of New York and containing the unoccupied so-called ring 1 and ring 2 houses, was excluded from the emergency declaration order.

The studies conducted at Love Canal by EPA included a major hydrogeologic investigation, and the collection and analysis of approximately 6,000 environmental samples consisting of water, soil, sediment, air and biota. An extensive quality assurance/quality control program was applied to all phases of the analytical work to document the precision and accuracy of the monitoring data. Strict chain-of-custody procedures were also employed to assure the integrity of the monitoring data.

The EPA multimedia environmental monitoring data revealed a limited pattern of environmental contamination in the area immediately adjacent to Love Canal, probably caused by localized and highly selective migration of toxic substances from the former canal to the vicinity of certain ring 1 residences. The data also revealed that contamination that had probably migrated from Love Canal was present in those storm sewer lines that originated near the former canal, and was present in area creeks and rivers (primarily in the sediment) at locations near to and downstream from the outfalls of those storm sewers.

Apart from these findings, the monitoring data revealed no clear evidence of environmental contamination in the area encompassed by the emergency declaration order that was directly attributable to the migration of substances from Love Canal. The data also provided no evidence, outside of ring 1, supporting the hypothesis that swales preferentially transported contaminants from the former canal into the surrounding neighborhood. Furthermore, the data revealed that the barrier drain system surrounding the landfill was effectively intercepting substances migrating laterally from the Love Canal and was drawing near-surface ground water back to the drains for collection and subsequent treatment.

In addition to the report presented in this Volume, two other Volumes have been prepared to document the Love Canal study. Volume II consists of a complete enumeration of all validated field samples collected at Love Canal and Volume III consists of a collection of statistical tabulations of the validated Love Canal monitoring data.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA-600/4-82-030a
May 1982

ENVIRONMENTAL MONITORING AT LOVE CANAL

Volume I

Office of Research and Development
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

i(a)

DISCLAIMER

This document was initiated prior to the Agency's recently instituted peer and policy review system. However, the report has been reviewed by many scientists within the U.S. Environmental Protection Agency, and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation of use.

The reader is cautioned to consider this report in its entirety. Reliance upon or use of any individual segment of this report without consideration of the whole document may be misleading and could possibly lead to erroneous conclusions.

FOREWORD

This report describes the results of a comprehensive multimedia environmental monitoring study conducted by the U.S. Environmental Protection Agency (EPA) at Love Canal, in Niagara Falls, New York. EPA was directed to conduct this study in response to a presidential state of emergency order that was declared at Love Canal on May 21, 1980. The purpose of this study, which was conducted during the summer and fall of 1980, was to provide an environmental data base on which decisions could be made regarding the habitability of residences in the Love Canal emergency declaration area. Due to the existence of a state of emergency at Love Canal, the design and field sampling portions of the project were completed under severe time constraints.

The monitoring program performed by EPA at Love Canal involved the collection and analysis of approximately 6,000 field samples, making the Love Canal study the most comprehensive multimedia monitoring effort ever conducted by EPA at a hazardous wastes site. The precision and accuracy of the environmental measurements obtained were documented through application of an extensive quality assurance program. As a result, this study exemplifies the design and execution of a state-of-the-art environmental monitoring program.

Volume I, Chapter 1, consists of an overview of the entire project and is intended to be accessible to a wide audience. The remainder of Volume I provides additional information concerning the design of the project and study findings. Technical details regarding specific aspects of the quality assurance programs used to validate the monitoring data are included as Appendixes to Volume I. Volumes II and III present the Love Canal monitoring data.

The EPA environmental monitoring data have been reviewed by the U.S. Department of Health and Human Services. The data from the organic chemical analyses have also been reviewed by the National Bureau of Standards (NBS). The results of these reviews are presented in a report entitled "Interagency Review: Comments by the U.S. Department of Health and Human Services and the National Bureau of Standards on the U.S. Environmental Protection

Agency's Love Canal Monitoring Study," available from the National Technical Information Service. Also included in that report is the EPA response to the NBS review.

In addition to the review performed by the National Bureau of Standards, the EPA Love Canal report was reviewed extensively by numerous Agency scientists. The results of these reviews have been incorporated in this final report, and have addressed all significant concerns expressed by the reviewers. The review comments did not affect the major finding of the EPA multimedia environmental monitoring study: namely, the data revealed no clear evidence of environmental contamination in the residential portions of the area encompassed by the emergency declaration order that was directly attributable to the migration of substances from Love Canal.

Courtney Riordan
Acting Assistant Administrator
for Research and Development

ABSTRACT

During the summer and fall of 1980 the U.S. Environmental Protection Agency (EPA) conducted a comprehensive multimedia environmental monitoring program in the vicinity of the inactive hazardous wastes landfill known as Love Canal, located in Niagara Falls, New York. As a result of a presidential state of emergency order issued on May 21, 1980, EPA was instructed to assess the extent and degree of environmental contamination that was directly attributable to the migration of substances from Love Canal into the occupied, residential area around the former canal defined by: Bergholtz Creek on the north; 102nd Street on the east and 103rd Street on the southeast; Buffalo Avenue on the south; and 93rd Street on the west. The area closest to the former canal, currently owned by the State of New York and containing the unoccupied so-called ring 1 and ring 2 houses, was excluded from the emergency declaration order.

The studies conducted at Love Canal by EPA included a major hydrogeologic investigation, and the collection and analysis of approximately 6,000 environmental samples consisting of water, soil, sediment, air, and biota. An extensive quality assurance/quality control program was applied to all phases of the analytical work to document the precision and accuracy of the monitoring data. Strict chain-of-custody procedures were also employed to assure the integrity of the monitoring data.

The EPA multimedia environmental monitoring data revealed a limited pattern of environmental contamination in the area immediately adjacent to Love Canal, probably caused by localized and highly selective migration of toxic substances from the former canal to the vicinity of certain ring 1 residences. The data also revealed that contamination that had probably migrated from Love Canal was present in those storm sewer lines that originated near the former canal, and was present in area creeks and rivers (primarily in the sediment) at locations near to and downstream from the outfalls of those storm sewers.

Apart from these findings, the monitoring data revealed no clear evidence of environmental contamination in the area encompassed by the emergency declaration order that was directly attributable to the migration of substances from Love Canal. The data also provided no evidence, outside of ring 1, supporting the

hypothesis that swales preferentially transported contaminants from the former canal into the surrounding neighborhood. Furthermore, the data revealed that the barrier drain system surrounding the landfill was effectively intercepting substances migrating laterally from Love Canal and was drawing near-surface ground water back to the drains for collection and subsequent treatment.

In addition to the report presented in this Volume, two other Volumes have been prepared to document the Love Canal study. Volume II consists of a complete enumeration of all validated field samples collected at Love Canal and Volume III consists of a collection of statistical tabulations of the validated Love Canal monitoring data.

CONTENTS

Page

Foreword iii
Abstract v
Figures ix
Tables xii
Abbreviations and Symbols xv
Acknowledgments xviii

CHAPTER 1 Overview 1
1.1 The EPA Monitoring Program 6
1.1.1 Selection of Sampling Sites 6
1.1.2 Samples Collected 8
1.1.3 Statistical Analysis of the Data 9
1.1.4 Substances Monitored 12
1.1.5 Sampling Procedures and Sites Sampled . . 13
1.1.6 Limitations 16
1.2 Results 18
1.3 Conclusions 21

CHAPTER 2 Background 23
2.1 Site Location 23
2.2 Site History 24

CHAPTER 3 Design of the Monitoring Studies 34
3.1 Objectives 34
3.2 Implementation 35
3.3 Quality Assurance/Quality Control (QA/QC) and Data Validation 39
3.3.1 Limits of Detection and Quantitation . . . 43
3.3.2 Precision and Accuracy Goals 43
3.4 Data Analysis and Data Reporting 45
3.5 Limitations 47

CHAPTER 4 Results of the Investigations 49
4.1 Hydrogeologic Program 49
4.1.1 Geology of the Love Canal Area 50
4.1.1.1 Geological Setting 50
4.1.1.2 Topography and Drainage 54
4.1.1.3 Occurrence of Ground Water . . . 60

CONTENTS (continued)

Page

4.1.2 Geophysical Investigations 61
4.1.2.1 Objectives of the Geophysical Investigations 61
4.1.2.2 Major Results of the Geophysical Investigations 63
4.1.3 Hydrology of the Love Canal Area 63
4.1.3.1 Ground-Water Movement 66
4.1.3.2 Ground-Water Flow Modeling . . . 71
4.1.4 Implications of the Hydrogeologic Program Findings 73
4.2 Evidence of Contamination Movement 75
4.2.1 Ground-Water Contamination 77
4.2.1.1 Shallow System 77
4.2.1.2 Bedrock Aquifer 83
4.2.2 Soil Contamination 87
4.2.3 Sump Contamination 97
4.2.4 Sanitary and Storm Sewer Contamination . . 107
4.2.5 Surface Water and Stream Sediment Contamination 116
4.2.6 Air Contamination 123
4.3 Evidence of Other Environmental Contamination . . 144
4.3.1 Drinking Water Contamination 144
4.3.2 Food Contamination 147
4.3.3 Radioactive Contamination 149
4.3.4 Biological Monitoring of Contaminants . . 152
4.3.5 Dioxin (2,3,7,8-TCDD) 156

CHAPTER 5 Summary and Conclusions 162

Appendix A Lists of Substances Monitored at Love Canal . 166
Appendix B Comparative Data and Existing Standards for Substances Monitored at Love Canal 171
Appendix C Quality Assurance for Water Samples 221
Appendix D Quality Assurance for Soil, Sediment, and Biota Samples 245
Appendix E Quality Assurance for Air Samples 266
Appendix F Report on the Audit of Gas Chromatography/ Mass Spectrometry Data Provided by Love Canal Project Analytical Laboratories 287

FIGURES

Number Page

1 General Site Location Map 2
2 The General Love Canal Study Area 3
3 Detail of the General Love Canal Study Area 4
4 Sampling Areas 10
5 Love Canal Remedial Action Project Plan View 30
6 Remedial Project: Transverse View 31
7 Sample Page of the Data Listing Presented in Volume II 46
8 Well A (Overburden) Installation Site Codes 51
9 Well B (Bedrock) Installation Site Codes 52
10 Generalized Columnar Section of Geologic Units in Love Canal Area 55
11 Index Map Showing Location of Project Area and Physiographic Provinces 56
12 Location of Storm Sewers Near Love Canal 59
13 Three Dimensional Plot of Shallow Electromagnetic Conductivity Data from Canal Area 64
14 Site Map Showing Major Results of Geophysical Survey . 65
15 Completed Shallow (Overburden) Well 67
16 Completed Bedrock Well 68
17 Regional Lockport Dolomite Potentiometric Surface . . . 69
18 Lockport Dolomite Potentiometric Surface 70
19 Overburden Static Water Table 72
20 Well A Sampling Sites, Benzene, Maximum Concentrations 80
21 Well A Sampling Sites, Toluene, Maximum Concentrations 81
22 Well A Sampling Sites, γ-BHC, Maximum Concentrations . 82
23 Well B Sampling Sites, Benzene, Maximum Concentrations 84
24 Well B Sampling Sites, Toluene, Maximum Concentrations 85
25 Well B Sampling Sites, γ-BHC, Maximum Concentrations . 86
26 Soil Sampling Site Codes 88
27 Typical Soil Sampling Configuration Used at Each Site . 90
28 Soil Sampling Sites (First), Benzene, Maximum Concentrations 93
29 Soil Sampling Sites (Second), Benzene, Maximum Concentrations 94
30 Soil Sampling Sites, γ-BHC, Maximum Concentrations . . 95
31 Soil Sampling Sites, Cadmium, Maximum Concentrations . 96

FIGURES (continued)

Number Page

32 Sump Water Sampling Site Codes 99
33 Sump Water Sampling Sites, Benzene, Maximum Concentrations 104
34 Sump Water Sampling Sites, Toluene, Maximum Concentrations 105
35 Sump Water Sampling Sites, Y-BHC, Maximum Concentrations 106
36 Storm Sewer Sampling Site Codes 109
37 Storm Sewer Sediment Sampling Sites, Benzene, Maximum Concentrations 111
38 Storm Sewer Water Sampling Sites, Toluene, Maximum Concentrations 112
39 Storm Sewer Sediment Sampling Sites, Toluene, Maximum Concentrations 113
40 Storm Sewer Water Sampling Sites, Y-BHC, Maximum Concentrations 114
41 Storm Sewer Sediment Sampling Sites, Y-BHC, Maximum Concentrations 115
42 Surface Water and Stream Sediment Sampling Site Codes 117
43 Stream Sediment Sampling Sites, Benzene, Maximum Concentrations 118
44 Surface Water Sampling Sites, Toluene, Maximum Concentrations 119
45 Stream Sediment Sampling Sites, Toluene, Maximum Concentrations 120
46 Surface Water Sampling Sites, Y-BHC, Maximum Concentrations 121
47 Stream Sediment Sampling Sites, Y-BHC, Maximum Concentrations 122
48 Air Sampling Site Codes 125
49 Outside Air Sampling Sites, Benzene, Maximum Concentrations 130
50 Living Area Air Sampling Sites, Benzene, Maximum Concentrations 131
51 Basement Air Sampling Sites, Benzene, Maximum Concentrations 132
52 Concentration of Benzene in Living Area Air Samples Collected in Canal Area Residences 135
53 Concentration of Benzene in Living Area Air Samples Collected in Control Area Residences 136
54 Median Concentration of Benzene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas 137
55 Median Concentration of Toluene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas 138

FIGURES (continued)

Number		Page
56	Median Concentration of 1,1,2,2-Tetrachloroethylene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas	139
57	Median Concentration of Benzene Observed in Air for Each Sampling Campaign	141
58	Median Concentration of Toluene Observed in Air for Each Sampling Campaign	142
59	Median Concentration of 1,1,2,2-Tetrachloroethylene Observed in Air for Each Sampling Campaign	143
60	Drinking Water Sampling Site Codes	145
61	Drinking Water Sampling Sites, Chloroform, Maximum Concentrations	148
62	Oatmeal and Potatoes Sampling Site Codes	150
63	Biota Sampling Site Codes	154
64	Sampling Site Codes for Dioxin (2,3,7,8-TCDD)	157

TABLES

Number Page

1 Summary of Love Canal Field Samples 8
2 A Summary of Love Canal Sites Sampled and Represented in the Validated Data Base 14
3 Chemicals Disposed at Love Canal by Hooker Electrochemical Company (1942-1953) 25
4 Identification of EPA Laboratories and Project Subcontractors 36
5 Geophysical Methods and Applications 62
6 Frequency of Detection of Contaminants in Validated Love Canal Samples 76
7 Significant Differences Observed in Extent of Shallow System Ground-Water Contamination at Love Canal 79
8 Significant Differences Observed in Extent of Soil Contamination at Love Canal 91
9 Significant Differences Observed in the Extent of Sump Water Contamination at Love Canal 100
10 Significant Differences Observed in the Extent of Air Contamination at Love Canal 128
11 Three Highest Concentrations of Selected Compounds Observed in Regular Air Monitoring 133
12 Frequency of Detection of Contaminants in Additional Validated Love Canal Samples 146
13 Minimum Detection Levels for Particular Gamma-Emitting Radionuclides 151
14 Scope of the Biological Monitoring Program 153
15 Results of Storm Sewer Sediment Determinations for 2,3,7,8-TCDD 159
A-1 Substances Monitored in Love Canal Water/Soil/Sediment/Biota Samples 166
A-2 Substances Monitored in Love Canal Air Samples 169
B-1 Control Sites 172
B-2 U.S. Average Data 176
B-3 Air 177
B-4 Surface Water 178
B-5 Drinking Water 179
B-6 Biota 180
B-7 List of Compounds Found in Ambient Air Using TENAX 182

TABLES (continued)

Number Page

B-8 Average Daily Concentrations of Toxic Chemicals Found by Singh 197
B-9 Summary of Current Standards for Substances Monitored in Love Canal Air Samples 198
B-10 Analytical Results of Chloroform, Bromoform, Bromodichloromethane, and Dibromochloromethane, and Total Trihalomethanes in Water Supplies from NORS and NOMS 201
B-11 EPA National Drinking Water Regulations 202
C-1 Measured Method Detection Limits in Micrograms per Liter from Analyses of Laboratory Control Standards 229
C-2 Estimated Method Detection Limits for all Laboratories 230
C-3 Measured Method Detection Limits in Micrograms per Liter for Method 608 in Reagent Water 231
C-4 Percentages of Acceptable Performance Evaluation Results 233
C-5 Summary Statistics and Lower Control Limits for Methods 624 and 625 Surrogates from EMSL-Cincinnati Measurements 238
C-6 Relative Standard Deviations (RSD) for Organic Analytes in Laboratory Control Standards 242
C-7 Relative Standard Deviations (RSD) for Inorganic Analytes in Water Samples 243
D-1 Summary Statistics and Acceptance Limits for Modified Method 624 and Modified Method 625 Surrogates from all Laboratory Measurements 258
D-2 Relative Standard Deviations (RSD) for Organic Analytes in Laboratory Control Standards NBS Sediment 262
D-3 Relative Standard Deviations (RSD) for Metals Analytes in Laboratory Control Standards NBS Sediment 263
D-4 Mean Percent Recoveries and Standard Deviations of NBS Certified Values in SRM River Sediment 1645 264
E-1 Volatile Organics on TENAX 271
E-2 Pesticides on Foam Plugs 272
E-3 Detection Limits for Inorganics 273
E-4 Results from Analyses of Blank TENAX Samples 273
E-5 Results from Air TENAX Duplicate Samples 278
E-6 Results of Audits of Sampler Flow Rates 279
E-7 Results from the Analyses of Calibration Check Samples 279
E-8 Results from the Analyses of Calibration Check Samples by Level and Analytical System 281

TABLES (continued)

Number — Page

E-9 Approximate Concentrations of Calibration Check Samples 282
E-10 Summary of Results for Polyurethane Foam Check Samples 282
E-11 Results from the Analysis of Blind Audit Samples by ICAP 283
E-12 Results from the Analysis of National Bureau of Standards Standard Reference Materials by NAA 283
F-1 Summary of EMSL-Cincinnati Audit of Love Canal GC/MS Water Samples 289
F-2 Summary of the EMSL-Las Vegas and ERL-Athens Audit of Love Canal Soil and Sediment Samples 290
F-3 Summary of the Love Canal Water Data Audit 292
F-4 Summary of the Love Canal Soil and Sediment Audit . . . 292
F-5 Summary of Non-Target Compound Audit 296

ABBREVIATIONS AND SYMBOLS

ACEE	Acurex Corporation, Energy and Environment Division
ACGIH	American Conference of Governmental Industrial Hygienists
AES	Advanced Environmental Systems, Inc.
amu	atomic mass unit
B	Below limit of detection
BCL (BCL2, BCL3)	Battelle Columbus Laboratories
BHC	Hexachlorocyclohexane (benzenehexachloride)
CFR	Code of Federal Regulations
cm/s	centimeters per second
CMTL	Compuchem/Mead Technology Laboratories
DEC	New York State Department of Environmental Conservation
DOH	New York State Department of Health
DOT	New York State Department of Transporation
EMSL-Cin	U.S. EPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio
EMSL-LV	U.S. EPA Environmental Monitoring Systems Laboratory, Las Vegas, Nevada
EMSL-RTP	U.S. EPA Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina
EPA	United States Environmental Protection Agency
ERCO	Energy Resources Company, Inc.
ERL-Ada	U.S. EPA Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma
ERL-Athens	U.S. EPA Environmental Research Laboratory, Athens, Georgia
ERL-Corvalis	U.S. EPA Environmental Research Laboratory, Corvalis, Oregon
ERL-Duluth	U.S. EPA Environmental Research Laboratory, Duluth, Minnesota
eV	Electron volt
g	gram
GCA	GCA Corporation
GC/ECD	Gas chromatography/electron capture detector
GC/FID	Gas chromatography/flame ionization detector
GC/MS	Gas chromatography/mass spectrometry
GSRI (GSLA, GSNO)	Gulf South Research Institute
HERL-RTP	U.S. EPA Health Effects Research Laboratory, Research Triangle Park, North Carolina

ABBREVIATIONS AND SYMBOLS (continued)

HIVOL	High-volume sampler
Hooker	Hooker Chemicals and Plastics Corporation
HRGC/HRMS	High resolution gas chromatography/high resolution mass spectrometry
ICAP	Inductively coupled argon plasma (emission spectrometer)
IIT	IIT Research Institute
K	hydraulic conductivity
kg	kilogram
ℓ	liter
LCARA	Love Canal Area Revitalization Agency
LCS	Laboratory control standard
LD	Less than limit of detection
LOD	Limit of detection
LOQ	Limit of quantitation
m	meter
μg/kg	micrograms per kilogram
μg/ℓ	micrograms per liter
$\mu g/m^3$	micrograms per cubic meter
mg/kg	milligrams per kilogram
mg/ℓ	milligrams per liter
mg/m^3	milligrams per cubic meter
MWRI	Midwest Research Institute
MS	Mass spectrometer
NA	Not analyzed
NAA	Neutron Activation Analysis
NAI	Negative agreement index
NASN	National Air Surveillance Network
NBS	National Bureau of Standards
NF	Not found
ng	nanograms
ng/kg	nanograms per kilogram
ng/ℓ	nanograms per liter
ng/m^3	nanograms per cubic meter
nm	nanometer
NIOSH	National Institute of Occupational Safety and Health
NOMS	National Organics Monitoring Survey
NORS	National Organics Reconnaissance Survey of Halogenated Organics
NPDES	National Pollutant Discharge Elimination System
NTIS	National Technical Information Service
NUSN	National Urban Soil Network
NYS	State of New York
OMSQA	U.S. EPA Office of Monitoring Systems and Quality Assurance
OSHA	U.S. Occupational Safety and Health Administration
PAI	Positive agreement index
PCB	Polychlorinated biphenyl
pCi	picocuries

ABBREVIATIONS AND SYMBOLS (continued)

PE	Performance evaluations
PEDC	PEDCo Environmental, Inc.
PFOAM	Polyurethane foam
PJBL	PJB/Jacobs Engineering Group, Inc.
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
QA/QC	Quality assurance/quality control
QAB	Quality Assurance Branch, EMSL-Cin
RSD	Relative standard deviation
SD	Standard deviation
SDWA	Safe Drinking Water Act
SRM	Standard Reference Material
SWRI	Southwest Research Institute
T	trace
TCDD	Tetrachlorodibenzo-p-dioxin
TENAX	TENAX sorbent
THM	Trihalomethanes
TLV	Threshold limit value
TOC	Total organic carbon
TOX	Total organic halogens
TRW	TRW, Inc.
TWA	Time-weighted average
WSU	Wright State University

ACKNOWLEDGMENTS

The writing of this report was accomplished through the exceptional efforts of John Deegan, Jr. As Project Coordinator, he provided the leadership that was essential to develop a coherent and understandable record of what was done at Love Canal, to determine the significance of the monitoring results, and to produce this report. As On-Scene Coordinator, he capably and articulately represented the Agency during a period of extreme stress, and was responsive to the concerns of local residents.

In a project of this magnitude it is impossible to acknowledge the individual contributions of the numerous other participants without inadvertently omitting someone. Therefore, a general acknowledgment of the immense commitment of time and energy contributed by the hundreds of EPA and contractor personnel involved in the conduct of this study must suffice, including members of: the U.S. EPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio (EMSL-Cin), Robert L. Booth, Acting Director; the U.S. EPA Environmental Monitoring Systems Laboratory, Las Vegas, Nevada (EMSL-LV), Glenn E. Schweitzer, Director; the U.S. EPA Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina (EMSL-RTP), Thomas R. Hauser, Director; the U.S. EPA Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma (ERL-Ada), Clinton W. Hall, Director; and the GCA Corporation, Leonard M. Seale, General Manager, Technology Division, and subcontractors. The dedication of these people to the task was essential for the study's completion.

Because of the important contributions certain individuals made to this project their efforts deserve to be identified. To begin with, the overall management of this project was the responsibility of Courtney Riordan, Director of the Office of Monitoring Systems and Quality Assurance (OMSQA). Without his continued oversight and guidance, this project would not have been completed satisfactorily. The Project Director for the field monitoring portion of the project was Thomas R. Hauser, EMSL-RTP; Steven M. Bromberg, EMSL-RTP was the Project Officer.

The following individuals also made major contributions to the project: William L. Budde (QA Officer for water analyses, Appendixes C and F) and John A. Winter (QA water samples) EMSL-Cin; Steven K. Seilkop (statistical analysis and consulting), EMSL-RTP; Jack W. Keeley, D. Craig Shew, and Jerry T. Thornhill, ERL-Ada and Paul Beam, Office of Water and Waste Management (hydrogeologic program); Gerald G. Akland and Terrence Fitz-Simons (statistical consulting), Thomas A. Hartlage (air sampling), Thomas C. Lawless (data management), and John C. Puzak (QA Officer for air analysis, Appendix E), EMSL-RTP; Stuart C. Black (QA Officer for soil/sediment/biota analyses), Kenneth W. Brown (water/soil/sediment/biota sampling), Eugene P. Meier, John A. Santolucito, Andrew D. Sauter, and Allan E. Smith (radiation program), EMSL-LV; W. Lamar Miller and R. Charles Morgan, Office of Solid Waste and Emergency Response; James D. Bunting and William J. Walsh, Office of Legal and Enforcement Counsel; Thomas G. McLaughlin, Robert B. Medz, and Frode Ulvedal, Office of Research and Development; Robert L. Harless (dioxin analyses) and Robert G. Lewis, HERL-RTP; James R. Marshall, EPA Region II; John Warren (statistical consulting), Office of Policy and Resource Management; Robert M. Bradway, David R. Cogley, Rose Mary Ellersick, and Kenneth T. McGregor, GCA Corporation; C. Stephen Kim, New York State Department of Health (NYS DOH); and Joseph L. Slack, New York State Department of Environmental Conservation (NYS DEC).

In many ways, the success of the entire program was dependent on those individuals at the EPA Love Canal Field Office who assisted during the monitoring portion of the project. The able staff at the EPA Love Canal Field Office included: Christine H. White, Helen E. Burnett, Michael A. Cinquino, and Sharon J. Thompson.

Above all others, however, the involvement of the concerned residents of Love Canal throughout the course of this project must be acknowledged. Without their support, suggestions, and cooperation this study could never have even been initiated, let alone completed.

CHAPTER 1
OVERVIEW

On May 21, 1980 President Carter issued an order declaring that a state of emergency existed in the area of Niagara Falls, New York known as Love Canal (Figure 1). This order was issued out of concern that toxic chemical wastes, which had been buried in a once partially excavated and now filled canal, were contaminating the adjacent residential areas and were subjecting residents to increased health risks. As a result of this order, the United States Environmental Protection Agency (EPA) was directed to design and conduct a comprehensive environmental monitoring program at Love Canal that would: (1) determine the current extent and degree of chemical contamination in the area defined by the emergency declaration order (Figure 2); (2) assess the short-term and long-term implications of ground-water contamination in the general vicinity of Love Canal; and (3) provide an assessment of the relative environmental quality of the Love Canal emergency declaration area.

The emergency declaration order of May 21, 1980 affected approximately 800 families residing in the horseshoe shaped area in Figure 2 labeled "DECLARATION AREA." In Figure 3, the outer boundary of the Declaration Area is defined by Bergholtz Creek on the north, 102nd Street and 103rd Street on the east and southeast (respectively), Buffalo Avenue on the south, and 93rd Street on the west. It should be noted that the emergency declaration order of May 21, 1980 excluded the area in Figure 2 labeled "CANAL AREA."

In this report, the Canal Area is the area bordered on the north by Colvin Boulevard, 100th Street on the east, Frontier Avenue on the south, and (approximately) 97th Street on the west. The Canal Area contains the residences located on both sides of 97th and 99th Streets. In 1978 the State of New York (NYS) acquired all but 2 of the 238 houses in the Canal Area (including a few houses on the north side of Colvin Boulevard), restricted virtually the entire Canal Area from public access by means of a guarded 8-foot high cyclone fence, and closed the public elementary school on 99th Street. The houses in the Canal Area consist of the so-called "ring 1" and "ring 2" houses. Those 99 houses whose backyards adjoin the inactive landfill have been referred

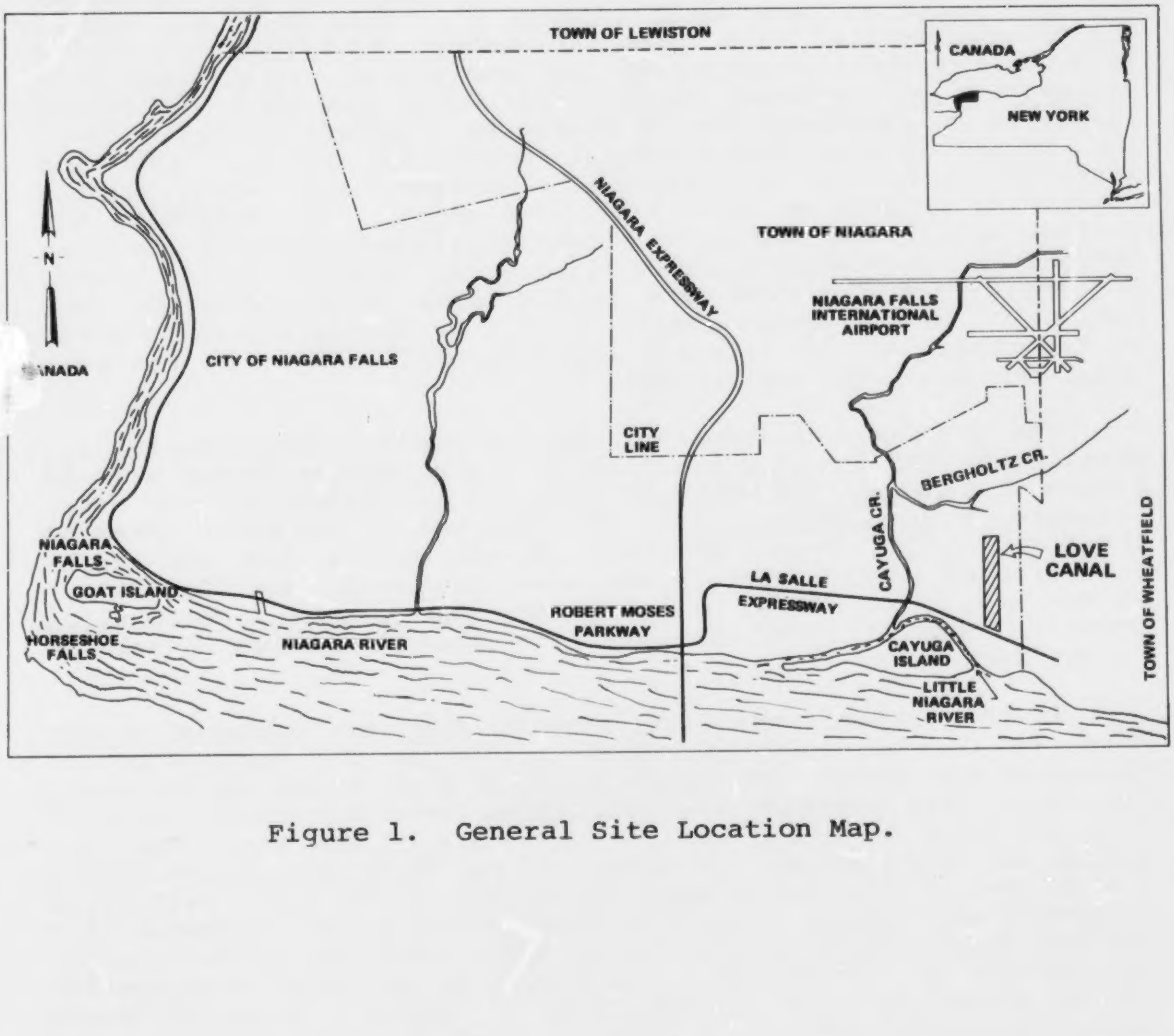

TOWN OF LEWISTON
CANADA
NEW YORK
N
NIAGARA EXPRESSWAY
TOWN OF NIAGARA
NIAGARA FALLS INTERNATIONAL AIRPORT
CANADA
CITY OF NIAGARA FALLS
CITY LINE
BERGHOLTZ CR.
CAYUGA CR.
LOVE CANAL
TOWN OF WHEATFIELD
NIAGARA FALLS
GOAT ISLAND
LA SALLE EXPRESSWAY
ROBERT MOSES PARKWAY
HORSESHOE FALLS
NIAGARA RIVER
CAYUGA ISLAND
LITTLE NIAGARA RIVER

Figure 1. General Site Location Map.

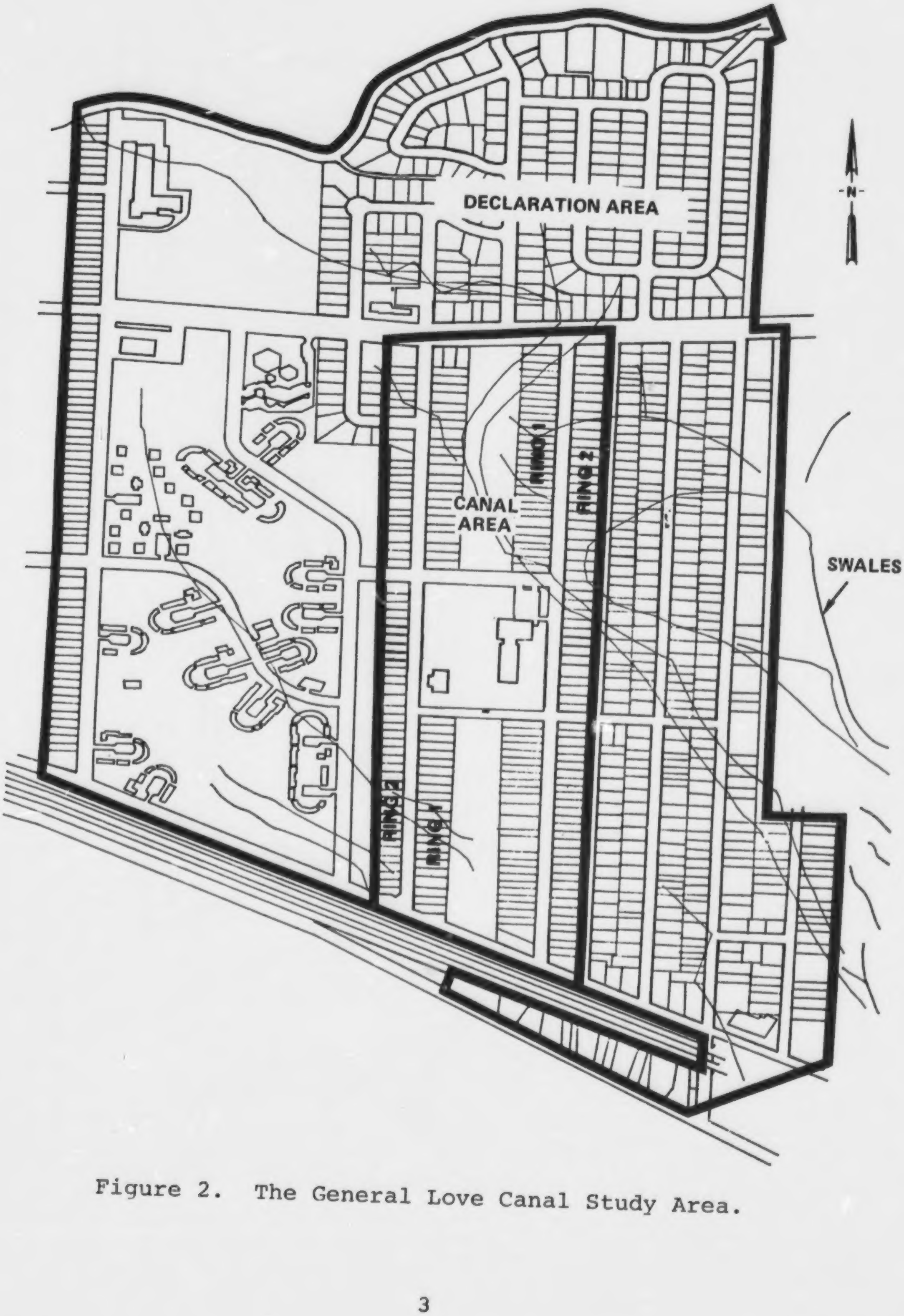

DECLARATION AREA
N
CANAL AREA
RING 1
RING 2
RING 2
RING 1
SWALES

Figure 2. The General Love Canal Study Area.

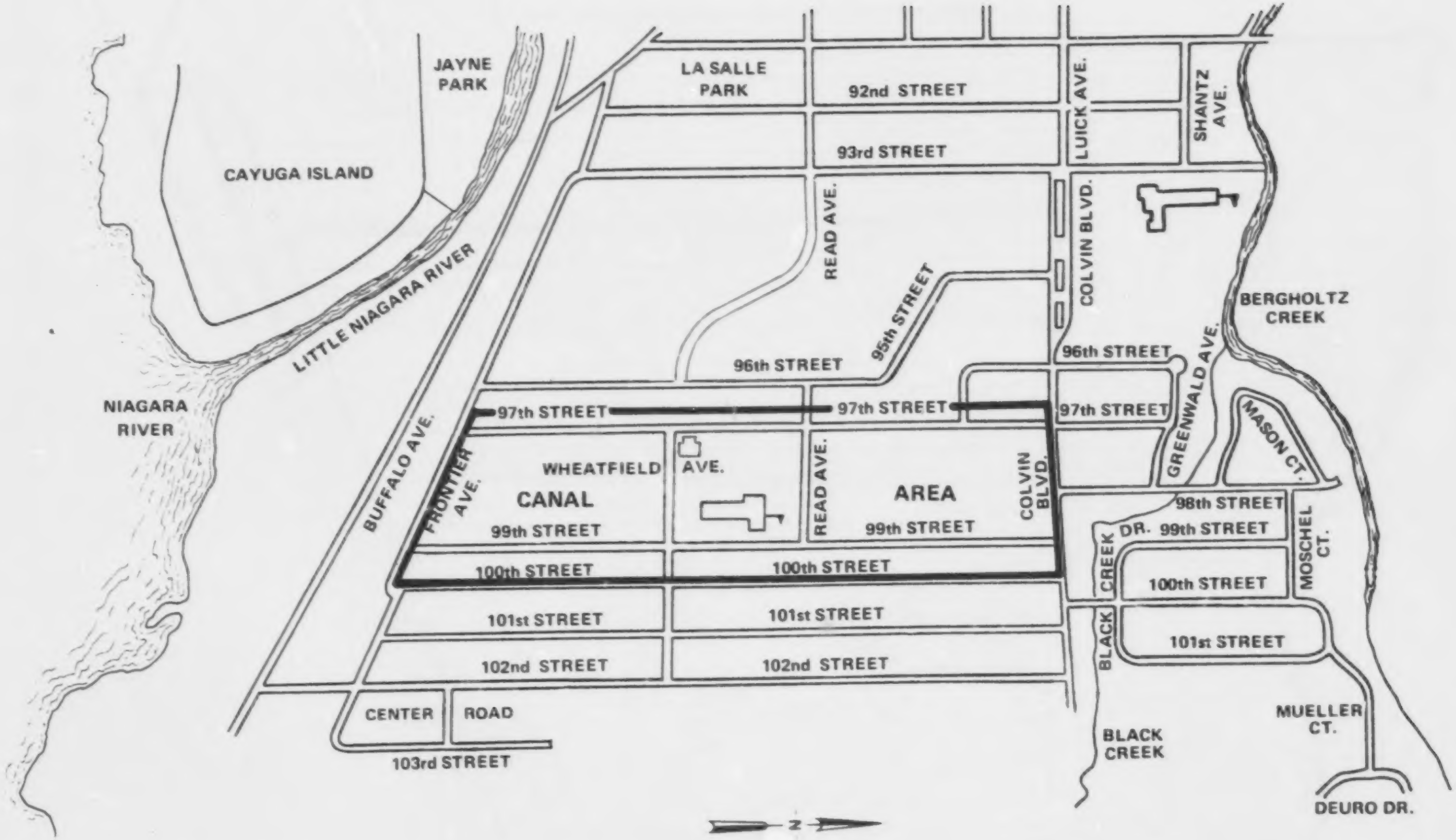

JAYNE PARK
CAYUGA ISLAND
LITTLE NIAGARA RIVER
NIAGARA RIVER
LA SALLE PARK
92nd STREET
93rd STREET
LUICK AVE.
SHANTZ AVE.
READ AVE.
COLVIN BLVD.
95th STREET
96th STREET
BERGHOLTZ CREEK
GREENWALD AVE.
97th STREET
MASON CT.
BUFFALO AVE.
FRONTIER AVE.
WHEATFIELD AVE.
CANAL
AREA
99th STREET
98th STREET
DR.
MOSCHEL CT.
100th STREET
CREEK
101st STREET
BLACK
102nd STREET
CENTER ROAD
103rd STREET
BLACK CREEK
MUELLER CT.
DEURO DR.
N

Figure 3. Detail of the General Love Canal Study Area.

to as ring 1 houses, while the houses on the east side of 99th Street, on the west side of 97th Street, and immediately opposite the landfill on the north side of Colvin Boulevard were referred to as ring 2 houses. (See Figure 2). The former canal was located in the area encircled by the ring 1 houses and at one time was approximately 3,000 feet long, 80 feet wide, and has been estimated to have been from 15 to 30 feet deep.

The 800 families residing in the Declaration Area lived within approximately 1,500 feet of the former dump site. Of these 800 families, approximately 550 lived in single-family dwellings (located mainly to the north and east of the Canal Area), 200 lived in a multiple-family complex of apartment buildings known as the La Salle Development (located to the west of the Canal Area), and 50 lived in a cluster of senior citizen garden apartments (also located to the west of the Canal Area). As part of the emergency declaration order, all persons residing in the Declaration Area were eligible for temporary relocation, at U.S. government expense, for a period of up to 1 year while environmental monitoring was conducted. Approximately 300 families (or an eligible member of a family) took part in the temporary relocation program. The temporary relocation program was managed and funded by the Federal Emergency Management Agency.

On October 1, 1980 President Carter and Governor Carey of New York signed an agreement providing $20 million for the voluntary permanent relocation of all residents living in the Love Canal Declaration Area. An agency of the State of New York, the Love Canal Area Revitalization Agency (LCARA), was established to manage the permanent relocation program and to plan for future use of the acquired properties. As of May 1, 1982 LCARA records revealed that approximately 570 families had been permanently relocated out of the Love Canal Declaration Area.

The EPA Love Canal final report consists of this Volume and two companion Volumes. This Volume contains a description of the design of the monitoring studies, the results of the investigations, a summary of the major findings, and conclusions and recommendations. Volume II consists of a complete listing of the analytical results obtained from all validated field samples collected at Love Canal. Volume III contains a set of statistical tabulations that summarize the Love Canal monitoring data according to various geographical areas of interests, and thus characterizes the extent and degree of environmental contamination in the Love Canal Declaration Area. Other documentation is also available that describes in detail certain aspects of the EPA Love Canal monitoring program which are only briefly reported here. This documentation has been prepared under contract, and is available to the public through the National Technical Information Service (NTIS). The material consists of: (1) an extensive four volume set of sampling and analytical protocols and quality assurance procedures entitled Quality Assurance Plan, Love Canal Study, LC-1-619-026, by GCA Corporation; (2) a report entitled

Love Canal Monitoring Program, GCA QA/QC Summary Report, by GCA Corporation; (3) a report entitled Geophysical Investigation Results, Love Canal, New York, by Technos, Inc.; (4) a report entitled The Ground-Water Monitoring Program at Love Canal, by JRB Associates; and (5) a report entitled Final Report on Ground Water Flow Modeling Study of the Love Canal Area, New York, by Geotrans, Inc.

1.1 THE EPA MONITORING PROGRAM

The EPA multimedia environmental monitoring program at Love Canal was designed and conducted under the direction of the Office of Research and Development, through its Office of Monitoring Systems and Quality Assurance (OMSQA). Contract costs for the project were \$5.4 million. GCA Corporation of Bedford, Massachusetts was the prime management contractor. A total of 18 subcontractors were involved in sample collection and analytical laboratory work.

Field sampling activities were started at Love Canal on August 8, 1980 and were concluded on October 31, 1980. During that time period, more than 6,000 field samples were collected and subsequently analyzed for a large number of substances known (or suspected) to have been deposited in the inactive hazardous wastes landfill. The analyses performed on the samples collected at Love Canal resulted in the compilation of approximately 150,000 individual measurements of environmental contamination levels in the general Love Canal area. A comprehensive quality assurance/ quality control (QA/QC) program, involving the analysis of 5,743 QA/QC samples, was applied to all phases of the analytical work performed during the project to document the precision and accuracy of the analytical results. Detailed reports describing the QA/QC programs are included as Appendixes C through E of this Volume. The integrity of the data was assured through the use of strict chain-of-custody procedures that fully documented the collection, transportation, analysis, and reporting of each Love Canal sample.

1.1.1 Selection of Sampling Sites

The selection of sampling locations was designed to accomplish three objectives: first, to monitor the Declaration Area using a statistically valid sampling design so that estimates of characteristic environmental concentrations of contaminants could be obtained; second, to locate and trace pathways of chemicals that had migrated from the former canal; and third, to obtain multimedia environmental measurements for the purpose of validating the presence of suspected transport pathways. In order to achieve these objectives, the following guidelines were used for site selection purposes.

1. Written permission of the property owner/occupant had to be obtained prior to initiating sampling activities at any site.

2. Simple random sampling of sites was to be employed to obtain representative coverage of the entire Love Canal Declaration Area.

3. Suspected transport pathways (based on information obtained from prior investigations conducted at Love Canal) were to be sampled as close to the former canal as was possible, and followed away from the former canal as far as was feasible. This sampling was performed in order to ascertain if contamination in the Declaration Area was directly attributable to Love Canal.

   Pathways sampled included:

   a. swales--former low-lying soil features in the vicinity of Love Canal that surface-water runoff once preferentially followed. The locations of known former swales in the general Love Canal area are identified in Figure 2.

   b. wet areas--residential areas where standing surface water once tended to accumulate (the NYS wet/dry designation was used for classification purposes).

   c. sand lenses--sandy deposits in soils through which ground water could readily move.

   d. buried utilities--storm and sanitary sewers that were located in close proximity to the canal.

   e. other pathways--information obtained from local residents directed sampling activities to numerous areas of suspected chemical migration.

4. Creeks and rivers in the general vicinity of Love Canal (particularly near storm sewer outfalls in Black Creek and the Niagara River) were to be sampled to determine the extent and degree of contamination in those waters resulting from the discharge of contaminated water and sediment from storm sewer lines, or from other (unknown) sources.

5. Multimedia measurements were to be conducted at selected sampling sites.

6. Control sampling sites were to be selected such that they were physically similar to Declaration Area sites, except that they were to be sufficiently distant from the former canal so as to be free from potential contamination related directly to Love Canal, and not be located near any other known hazardous waste landfill areas. Control sites were selected throughout the greater Niagara Falls area, and on Grand Island (located south of Niagara Falls). See Table B-1 in Appendix B for more detailed information on the location of control sites.

7. Indoor air monitoring was to be performed only in unoccupied residences in order to reduce the potentially confounding influence of airborne contaminants that might be present due to habitation activities.

1.1.2 Samples Collected

A total of 6,853 field samples were collected by EPA during the Love Canal monitoring program. Of these samples 6,193 were analyzed and 5,708 were validated through application of an extensive QA/QC program, which involved the analysis of an additional 5,743 QA/QC samples. In total, the validated Love Canal data base contains the results from analyses performed on 11,451 samples (field samples plus QA/QC samples). Table 1 reports the number of field samples collected, analyzed, and validated according to each environmental medium sampled.

TABLE 1. SUMMARY OF LOVE CANAL FIELD SAMPLES

Medium	Samples Collected	Samples Analyzed	Samples Validated	Percent Rejected by QA/QC	Percent Other[†]	Percent Validated
Water	2,687	2,457	2,065	14.6	8.5	76.9
Soil	1,315	1,156	1,132	0.7	13.2	86.1
Sediment	290	266	259	2.4	8.3	89.3
Air	2,089	2,024	1,967	2.6	3.2	94.2
Biota	472	293	285	1.5	38.1	60.4
Totals	6,853	6,193	5,708	6.8	9.9	83.3

[†] Includes samples that were damaged, lost, not reported, etc.
Note: Percentages are based on the number of samples collected.

The Declaration Area was subdivided into 10 sampling areas that facilitated the use of statistical estimates of typical environmental concentration levels of substances monitored throughout various sections of the general Love Canal area. Sampling areas were defined (as feasible) according to those natural and manmade physical features of the Declaration Area that might be related to chemical migration pathways. Consequently, the likelihood was increased of more readily permitting the potential identification of chemical concentration gradients of substances that had migrated from the former canal. Typical physical boundaries of the sampling areas included: (1) streets, whose buried utilities (such as storm sewer lines) might serve as barriers to, or interceptors of, the subsurface migration of chemicals, and whose curb drains would serve as barriers to or collectors of overland flow; and (2) creeks, which serve as natural recharge/discharge boundaries to the shallow ground-water system in the area. Within each of the 10 sampling areas, sites were both intentionally selected to maximize the probability of detecting transport pathways (for example, purposely locating sampling sites in former swales, sand lenses, and wet areas), and randomly selected to provide a statistically representative sample of residences. The fenced Canal Area compound was also sampled, and was identified as sampling area 11. Figure 4 depicts graphically the boundaries of sampling areas 1 through 11.

In addition to the 11 geographical sampling areas just described, a number of other sites outside the Declaration Area were sampled and, for convenience, have been grouped according to sampling area designations (even though they do not necessarily refer to physically contiguous geographical areas). For example, sampling area 97 consisted of those sites located outside the boundary of the Declaration Area that were sampled at the explicit request of area residents. Sampling area 97 sites were not considered control sites. Another sampling area, referred to as 98, consisted of sites (including one site in the Declaration Area) that were intentionally selected for a special ambient-air monitoring study to determine transport patterns and background levels of airborne pollutants. Finally, sampling area 99 consisted of those sites explicitly selected as control sites for each environmental medium sampled, and those sites that were explicitly selected as control sites for comprehensive multimedia sampling. Due to the distance of sampling area 99 sites from the Declaration and Canal Areas, they are often not displayed in subsequent figures identifying medium-specific sampling locations.

Both the number of sites sampled and the number of samples collected in each sampling area varied according to the environmental medium sampled. Air was the only medium for which there was an explicit attempt to sample an equal number of sites in each sampling area. For all other media, the intensity of sampling in a sampling area was a function of distance from the former canal (that is, sampling intensity decreased with distance), availability of the medium for sampling purposes (for example, the sampling of sump water was contingent on the presence of a sump in a residence), and the appropriateness of the sampling area approach for the medium sampled. As an illustration of this last point, note that the sampling area approach to characterizing bedrock ground-water quality was rejected as inappropriate because bedrock ground-water movement was recognized as obviously not constrained by street boundaries.

1.1.3 Statistical Analysis of the Data

In order to perform statistical analyses on the monitoring data, the data were aggregated (by medium and sample source) according to Declaration Area (sampling areas 1 through 10), Control Area (sampling area 99), and Canal Area (sampling area 11).

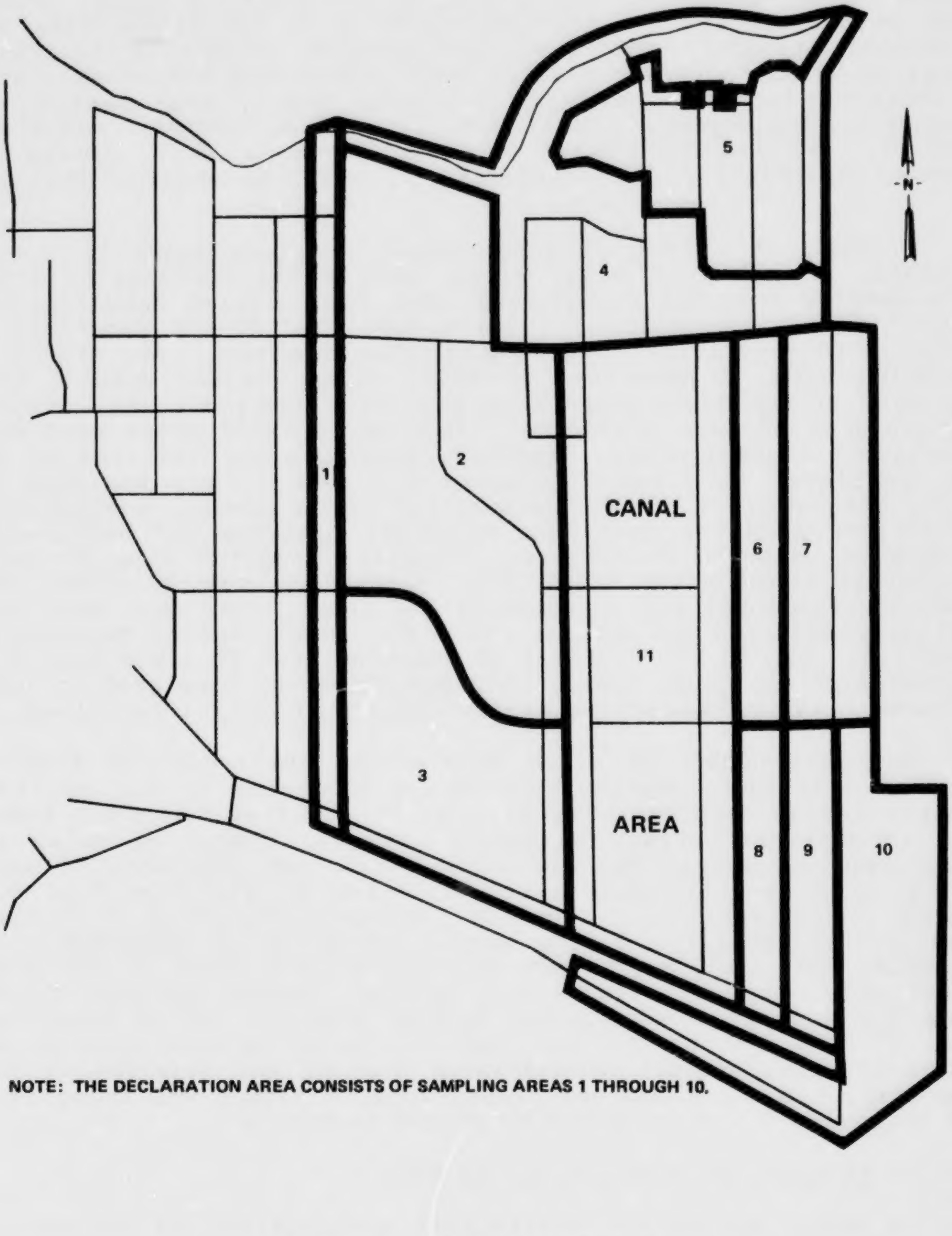

5
N
4
2
1
CANAL
6
7
11
3
AREA
8
9
10
NOTE: THE DECLARATION AREA CONSISTS OF SAMPLING AREAS 1 THROUGH 10.

Figure 4. Sampling Areas.

The statistical tabulations and analyses performed on the aggregated monitoring data (presented in Volume III) consisted of substance-by-substance comparisons of frequencies of detections and median concentration levels observed in each of the three data aggregating units (that is, Declaration, Control, and Canal Areas).

The extent of environmental contamination in an area of interest (for example, the Declaration Area) was defined as the percentage of times a substance was identified as present at a "trace" or greater concentration level in the field samples analyzed and validated. A difference of percentages test, using Fisher's exact test to compute probability values, was used to determine if statistically significant differences in the extent of chemical contamination existed between the three aggregating units. (See, for example, Y. M. M. Bishop, S. E. Fienberg, and P. W. Holland, Discrete Multivariate Analysis, M. I. T. Press, 1975, 364). The degree of environmental contamination in an area of interest was defined as the median concentration of all field sample measurements for a substance in the aggregating unit of interest. A difference of medians test, using Fisher's exact test to compute probability values, was used to determine if statistically significant differences in the degree of chemical contamination levels existed between the Declaration, Control, and Canal Areas. (See, for example, A. M. Mood, F. A. Graybill, and D. C. Boes, Introduction to the Theory of Statistics, McGraw-Hill, 1974, 521).

Other statistical procedures used to summarize the vast amount of data collected at Love Canal by EPA and presented in Volume III consisted of grouping the data into frequency distributions, with intervals defined according to the concentration levels observed; computing various percentiles of interest; reporting finite (quantified) minimum and maximum observed concentrations; and computing the mean (arithmetic average) value of the observed finite concentrations.

The statistical criteria used to aid in a determination of the presence of Love Canal-related environmental contamination in the Declaration Area were designed to achieve three objectives: (1) test the validity of the postulated process of contaminant movement from the former canal into the Canal Area, and from the Canal Area into the Declaration Area; (2) safeguard the public health by establishing a requirement of using only lenient statistical evidence (that provides a margin of safety) to assess the extent and degree of contamination in the Declaration Area; and (3) obtain acceptably high power in the statistical tests employed that might otherwise have been affected adversely (in certain instances) by the relatively small number of control sites samples that could be collected during the short sampling time period available for conducting this study.

1.1.4 Substances Monitored

Due to time and budgetary constraints, the EPA monitoring program at Love Canal was intentionally directed at the identification of a finite number of chemicals in each sample collected. In order to increase the efficacy of this approach, efforts were devoted to developing lists of targeted substances that would be routinely monitored in each specific sample type collected at Love Canal. To this end, the following activities were conducted: (1) samples of air and leachate were collected by EPA directly at the former canal prior to the initiation of field sampling activities and were analyzed comprehensively; (2) the results from previous environmental monitoring studies conducted at Love Canal by the State of New York and EPA were reviewed; and (3) records submitted by the former owner of the site, Hooker Chemical and Plastics Corporation (concerning the 21,800 tons of chemical wastes buried in the landfill) were examined. These efforts permitted EPA to identify those substances that were most abundant in the source, prevalent in the environment, and of toxicological significance. The end result was the construction of 2 lists of targeted substances; a list of approximately 150 substances for water/soil/sediment/biota samples; and a list of 50 substances for air samples. The specific substances monitored at Love Canal are listed in Tables A-1 and A-2 in Appendix A of this Volume.

The EPA monitoring program conducted at Love Canal represents a directed, comprehensive effort in environmental monitoring at a hazardous wastes site. Due to the large number of environmental samples analyzed and the large number of targeted substances monitored, it is unlikely that significant amounts of contaminants that had migrated from Love Canal would have been undetected. Furthermore, the intentional inclusion of specific substances on the target list that were known to be present in Love Canal, and which (due to their physical and chemical properties) might also serve as effective and efficient indicators of subsurface migration of leachate, was designed to permit a determination and assessment of chemical migration from the source.

The EPA monitoring program at Love Canal also included the following two features. First, analytical subcontractors were required to analyze each field sample for all targeted substances, and were also required to identify the next 20 most abundant substances found in the sample. Second, EPA conducted an audit of the results obtained by analytical subcontractors, in order to determine the accuracy of substance identifications and completeness of substance identifications in those field samples analyzed by the subcontractors. The results of the audit, reported in Appendix F of this Volume, provided additional confirmation of the validity of the analytical chemistry data presented in this report.

1.1.5 Sampling Procedures and Sites Sampled

A total of 174 ground-water monitoring wells were installed by EPA at Love Canal and at control sites. Samples of ground water were obtained from 136 of the monitoring wells. The remaining 38 wells were either dry or the sample results were rejected by the data validation and QA/QC process.

Two separate ground-water systems exist in the Love Canal area and were monitored individually. A shallow overburden system was often encountered, usually at a depth of less than 20 feet below the land surface. Wells installed to monitor the shallow system were referred to as "A Wells." Ground-water samples collected from a total of 79 A Wells are included in the validated data base. The major aquifer present in the Love Canal area is located in the underlying Lockport Dolomite bedrock, a unit that was encountered typically at a depth of approximately 40 feet below the land surface. The major water bearing zone of the dolomite was found to occupy approximately the top 20 feet of the unit. The bedrock aquifer was sampled separately through the installation of bedrock wells, referred to as "B Wells." Ground-water samples collected from a total of 57 B Wells are included in the validated data base. Most sites sampled had both A and B Wells installed.

A large number of other water samples were collected at Love Canal. These included: (1) residential drinking water (including both raw and finished water samples collected from the Niagara Falls Drinking Water Treatment Plant); (2) sanitary sewer water; (3) storm sewer water; (4) sump water; and (5) surface water from area creeks and rivers (sites in or near to the Declaration Area were usually located in proximity to storm sewer outfalls). A full enumeration of the number of water sampling sites that are represented in the validated data base is given in Table 2.

A total of 171 soil sampling sites are represented in the validated data base. The procedure used for collecting soil samples was designed to maximize the probability of detecting the subsurface migration of chemicals through soils. Because it was not possible to stipulate the soil depth at which leachate might move laterally from Love Canal, and/or percolate downwards through soils, the more permeable top 6 feet of soil was sampled. At each soil sampling site a total of 7 soil cores, each 6 feet long and 1 3/8 inches in diameter, were collected following a pattern (typically a circular shape) that was representative of the physical area sampled. Two of the seven soil cores were analyzed for the presence of targeted "volatile" compounds. The remaining five soil cores were composited and analyzed for additional targeted substances. A full enumeration of the number of soil sampling sites that are represented in the validated data base is given in Table 2.

TABLE 2. A SUMMARY OF LOVE CANAL SITES SAMPLED AND REPRESENTED IN THE VALIDATED DATA BASE

	Sampling Areas						Grand Total
	1-10	11	99	Sub-Total	97	98	
Water							
Drinking	31	3	5	39	5	--	44
Ground: A Wells	49	19	11	79	--	--	79
B Wells	29	13	15	57	--	--	57
Sanitary sewer	1	0	0	1	--	--	1
Storm sewer	22	3	1	26	2	--	28
Sump	33	13	1	47	7	--	54
Surface	4	--	5	9	10	--	19
Soil	112	24	9	145	28	--	171
Sediment							
Sanitary sewer	1	0	0	1	--	--	1
Storm sewer	18	4	1	23	1	--	24
Stream	4	--	5	9	9	--	18
Sump	--	3	--	3	--	--	3
Air							
Basement	9	1	0	10	--	--	10
Living	55	6	4	65	--	--	65
Outside	8	1	0	9	--	--	9
Transport study	--	--	--	--	--	5	5
Occupied/ Unoccupied study	3	0	0	3	4	--	7
Sump/Basement-Air study	0	9	0	9	--	--	9
Biota							
Crayfish	1	--	1	2	--	--	2
Dog hair	20	--	15	35	--	--	35
Maple leaves	14	6	11	31	--	--	31
Mice	5	2	2	9	--	--	9
Oatmeal	12	2	4	18	--	--	18
Potatoes	11	2	3	16	--	--	16
Worms	4	2	3	9	--	--	9

Note: Dashes signify not applicable

Sediment samples were collected from a number of different sources during the Love Canal monitoring program. Sediment samples were collected from area creeks and rivers, in conjunction with the collection of surface-water samples. As was noted earlier, sites in or near to the Declaration Area were usually located in proximity to storm sewer outfalls. In addition, sediment samples were collected, as available, from the following sources: (1) sanitary sewers; (2) storm sewers; (3) sumps; and (4) from the on-site Leachate Treatment Facility located adjacent to the former canal on 97th Street. A full enumeration of the number of sediment sampling sites that are represented in the validated data base is given in Table 2.

In addition to the organic and inorganic chemicals routinely determined in water/soil/sediment samples, EPA conducted a monitoring program to define and quantify the radionuclides present in the general Love Canal area. Those radionuclides analyzed for by EPA included all gamma-emitting radionuclides and, in drinking water samples, tritium.

Air monitoring at Love Canal was conducted in 65 continuously unoccupied residences. In each of these residences, living area air was monitored by means of collecting integrated 12-hour samples using the sorbents TENAX and polyurethane foam (PFOAM). A maximum of 13 daytime (6 a.m. to 6 p.m.) air sampling campaigns were conducted in each of these residences throughout the duration of the monitoring program. In addition to the normal daytime sampling campaigns, 3 nighttime campaigns (also of 12 hours duration) were conducted in some of these same residences. Each sampling area contained from four to eight living area air monitoring sites.

In 9 of the 65 air monitoring sites, basement air and outdoor (ambient) air were also monitored using the sorbents TENAX and PFOAM. In addition, outdoor sampling sites were monitored with high-volume (HIVOL) particulate samplers, which were started simultaneously with the TENAX and PFOAM samplers, and were operated for 24-hour periods. Air samples from basement and outdoor locations were collected in synchronization with the 13 regularly conducted living area air sampling campaigns.

Residences in which multiple air sampling locations were established were referred to as "base" residences. At each base residence, efforts were made to sample all environmental media and usually included indoor and outdoor air, ground water from both A and B Wells, drinking water, sump water, soil, and foodstuff introduced to the residence as part of the limited biological monitoring program conducted at Love Canal. All sampling areas immediately adjacent to the former canal contained one base residence. Due to limited availability of appropriate locations and residential structures, it was not possible to secure a control site that satisfied the requirements established to designate it a base residence.

Three special air monitoring research studies were also conducted at Love Canal. These studies involved an investigation of the airborne transportation of pollutants in the Niagara Falls area, the effects of domiciliary occupancy on indoor air pollution levels, and an examination of the interrelationship between contaminant concentration levels in basement sumps and basement air.

An enumeration of the number of air monitoring sites that are represented in the validated data base is given in Table 2.

A limited biological sampling program was conducted by EPA at Love Canal for the purpose of investigating the use of local biological systems to monitor the biological availability and biological accumulation of substances found in appropriate environmental media. The biota program involved the collection and analysis of a limited number of samples, including: (1) crayfish (40 composite samples); (2) domestic dog hair; (3) silver maple leaves; (4) field mice (100 samples); and (5) common earthworms (30 samples); as well as (6) purposely introducing foodstuff (oatmeal and potatoes) into the basements of base residences to determine their potential for accumulation of volatile organic compounds. The biological monitoring program was intentionally not directed at attempting to determine health or ecological effects of toxic chemicals in biota. A full enumeration of the number of biota sampling sites (approximately commensurate with the number of samples except for crayfish, mice, and earthworms) that are represented in the validated data base is given in Table 2.

1.1.6 Limitations

Even though EPA conducted a major sampling effort at Love Canal, resulting in the acquisition of a considerable amount of environmental monitoring data, it is acknowledged that the project was conceived, initiated, and conducted under severe budgetary and time constraints. It was recognized, however, that the critical nature of the problem at Love Canal, involving a large number of nearby residents, meant that the monitoring program conducted by EPA had to be initiated quickly, be thorough, and of high quality. Consequently, a number of decisions were made by EPA, concerning the design and conduct of the monitoring studies, that have potential influence on the interpretation of the study findings.

First, due to the size of the geographical area involved, a statistical survey design was formulated to determine the extent and degree of environmental contamination in the Declaration Area that was directly and incrementally attributable to the migration of toxic substances from Love Canal. Thus, for each environmental medium monitored, a sampling design with an appropriate sampling frame was employed for site selection. In all media, the sampling design used combined aspects of both purposive selection (for example, intentionally locating some sampling sites to maximize the probability of detecting chemicals that had migrated from Love Canal), and simple random sampling. Whenever possible, sampling sites were stratified according to geographical areas that were defined by natural or manmade physical boundaries, in order to facilitate the identification of potential spatial variability in contamination levels in the Declaration Area.

Second, a finite (but large) list of targeted substances was identified for monitoring in each environmental medium sampled.

Third, because a state of emergency existed at Love Canal, a 3-month time constraint (as opposed to 6 months, 1 year, or longer) was imposed on sampling. While this time frame limited the scope of the investigation, it still provided substantial information regarding potential environmental contamination hazards in the Declaration Area resulting directly from Love Canal.

Fourth, all routine living area air monitoring residences had to be unoccupied continuously throughout the study period, in order to control for the potentially confounding effects of household activities on indoor air pollution levels. By repetitively monitoring air, a 3-month time series of data was obtained that incorporated the potential for detecting temporal trends (for example, trends due to changes in temperature, humidity, precipitation, and wind direction) in concentration levels, and were sampled repetitively.

Fifth, all EPA sampling activities at Love Canal were dependent on the cooperation and willingness of area residents (and state and local authorities) to grant EPA written permission to sample on their property. In recognition of the importance of the EPA monitoring program to each individual, a high rate of cooperation (in excess of 90 percent) was generally displayed by Declaration Area residents.

Partially due to these factors, the ability to use the findings of the EPA monitoring program to predict future weather-influenced conditions at Love Canal may be limited. In similar fashion, the statistical limitations and uncertainties associated with all sampling designs (in contrast to a complete census involving environmental monitoring at all residences), are acknowledged. Consequently, any attempt to infer prior conditions in the Declaration Area (such as air pollution levels) from the current environmental monitoring data is risky and has not been performed.

1.2 RESULTS

The EPA ground-water monitoring program revealed no evidence of contamination attributable to Love Canal in the bedrock aquifer and only very localized contamination in the shallow system. In general, evidence of contaminated ground water that was directly attributable to the migration of substances from the former canal was found only in a few shallow system A Wells located immediately adjacent to Love Canal in the residential lots of some ring 1 houses. Clear evidence of ground-water contamination directly attributable to Love Canal was not found outside of the area around ring 1 houses or in the Declaration Area.

On the basis of tests conducted in monitoring wells, and a ground-water flow model constructed specifically according to hydrogeologic conditions encountered at Love Canal, it was determined that the barrier drain system (the Leachate Collection System) was functioning effectively. The barrier drain system was installed completely around Love Canal by the City of Niagara Falls and the State of New York in 1978 and 1979, as a containment remedy designed to halt the lateral migration of chemicals through the soil. In addition, a clay cap was placed on the landfill. The EPA findings suggested that the barrier drains were operating to intercept chemicals which might be migrating laterally from the former canal, to lower the hydraulic head in the former canal (preventing a so-called "bathtub overflow" effect), and to move nearby ground water towards the drains for collection and subsequent treatment. As a result of the drawback influence of the barrier drains, which extend approximately 1,700 feet in the more permeable sandy soils and 180 feet in the less permeable clays found in the area, nearly all nearby shallow system contamination should be recovered (assuming no additional attenuation of contaminants) that resulted from the prior migration of contaminants out of Love Canal.

The soil monitoring program yielded results that were consistent with the ground-water monitoring findings. In particular, clear evidence of soil contamination attributable to Love Canal was found only in the yards of a relatively few ring 1 houses, and tended to coincide with those sampling sites where contamination was also found in shallow system A Wells. The soil findings suggested that the consistent multimedia pattern of environmental contamination observed at certain ring 1 locations was due to the presence of local, highly heterogeneous soil conditions that permitted the relatively more rapid migration of contaminants from Love Canal to those locations. In particular, soil contamination directly attributable to the migration of contaminants from Love Canal was found to be confined to ring 1, and was associated with the discrete presence of sandy soil (for example, in the form of a sand lens), and with the relative abundance of more permeable fill materials (for example, filled swales). No evidence of soil contamination outside of ring 1 was found in support of the hypothesis that swales served as preferential routes of chemical migration from Love Canal. Furthermore, no patterns of soil contamination were found outside of ring 1, and no clear evidence of soil contamination was found in the Declaration Area, that could be directly attributed to the migration of contaminants from Love Canal.

Evidence of contamination in sump water and sump sediment samples was found in relatively few ring 1 houses. The ring 1 sites at which sump contamination was found tended to coincide with, or be located near to, those sites where contamination was found in shallow system A Wells and in soil samples. These sites were located mainly south of Wheatfield Avenue and on the 97th Street (west) side of Love Canal. Relatively high levels of contaminants were found in the few ring 1 sumps that contained an amount of sediment adequate for separate sampling and analysis purposes. No pattern of sump contamination was found outside of ring 1 houses, and no clear evidence of sump contamination was found in the Declaration Area that could be directly attributed to the migration of contaminants from Love Canal.

Samples of storm sewer water and sediment revealed that highly contaminated sediment and contaminated water were traceable from the Canal Area to local outfalls, and that approximate concentration gradients (for certain compounds) corresponding to storm-water flow directions existed. Because of the remedial actions taken at the site (and based on the findings of the hydrogeologic program), it is likely that only residual (that is, prior to remedial construction) contamination was found in the storm sewer lines. Furthermore, it is possible that the contamination found in the storm sewer lines near Love Canal resulted from the following: (1) infiltration of the storm sewer laterals on Read and Wheatfield Avenues that were connected (respectively) to the northward and southward flowing storm sewer lines on 97th Street, and the storm sewer lateral on Wheatfield Avenue that was connected to the southward flowing storm sewer line on 99th Street; (2) historical (that is, prior to remedial construction) overland flow of contaminated surface water and sediment that would have been collected by curb drains on all streets immediately adjacent to or crossing the former canal; (3) a catch basin and drain that was located near the former canal in the backyard of houses at 949-953 97th Street, and which emptied into the 97th Street northward flowing storm sewer line; and (4) by the discharge of contaminated water and sediment that was taken-up by the no longer operating sump pumps located in the basements of certain ring 1 houses, and discharged into the 97th and 99th Streets storm sewer lines.

Because of the relatively low solubility in water of many of the organic compounds monitored, and the continuing flow of water through the storm sewer lines, the concentration levels of organic compounds detected in storm sewer sediment samples were generally higher (due to certain organic compounds being more readily sorbed on sediment particles) than corresponding concentrations in storm sewer water samples. It should also be noted that sediment samples could not be collected at all storm sewer sites sampled, and that sediment tended to be more readily available for collection at storm sewer line junctions and turning points.

Surface-water samples and sediment samples collected from Love Canal area creeks and rivers revealed highly contaminated sediment and contaminated water in the general vicinity of those storm sewer outfall locations that were fed by lines connecting to the 97th and 99th Streets storm sewers. In particular, the sediment samples collected in Black Creek near the 96th Street storm sewer outfall revealed that high levels of toxic organic compounds were present, as did sediment samples collected in the Niagara River near the 102nd Street storm sewer outfall. Due to the close proximity of the 102nd Street landfill to water and sediment sampling sites in the Niagara River, it was not possible to unequivocally identify the source(s) of contaminated Niagara River sediment near the 102nd Street outfall.

The air monitoring program results were consistent with the findings obtained from monitoring other environmental media. In essence, indoor air contamination levels were elevated in a few ring 1 houses, namely those houses where other media monitoring efforts (for example, the special sump/basement air monitoring study) also identified the presence of contaminants that had migrated from Love Canal. Outside of the relatively few ring 1 houses so affected, no pattern of regular (living area) indoor, or basement air contamination was observed. Furthermore, no clear evidence of air pollution was found in the Declaration Area that could be directly attributed to contamination emanating from Love Canal.

The three special air monitoring research studies conducted at Love Canal provided limited evidence of the following results. First, airborne contaminants detected indoors were also detected in the outside ambient air, and may have been transported from upwind sources. Second, activities associated with domiciliary occupancy suggested that such activities could potentially increase indoor air pollution levels. And third, highly contaminated sumps (which were found in only a limited number of ring 1 residences) could serve as potential contributing sources of high levels of indoor air pollution.

Analyses of drinking water samples revealed that the drinking water sampled satisfied existing EPA drinking water quality standards. Furthermore, no drinking water samples collected in Declaration or Canal Area residences revealed the presence of contamination that was directly attributable to Love Canal.

The results of monitoring for radioactive contaminants in water/soil/sediment samples revealed that only normal background radioactivity was present in the Declaration Area and in the Canal Area. Analyses conducted indicated that the predominant gamma-emitting radionuclides observed were naturally occurring radionuclides such as radium-226 and the so-called daughter products of its radioactive decay. Water samples analyzed revealed that no gamma-emitting radionuclides were present above background levels, and drinking water concentrations of tritium were well below the EPA drinking water standard. Soil and sediment samples analyzed revealed the presence of only low levels of naturally occurring radionuclides such as potassium-40 and the daughter products of radium-226 and thorium-232, and low concentrations of cesium-137 comparable to worldwide fallout levels.

The limited biological monitoring program provided results that were consistent with the findings obtained from environmental monitoring activities. In general, no evidence of either biological availability or biological accumulation of environmental contaminants was observed among the species sampled in the Declaration Area that could be attributed directly to environmental contaminants that had migrated from Love Canal.

Finally, the results of a special monitoring program for the highly toxic compound 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), revealed evidence of limited environmental contamination in the general Love Canal area. In particular, it was determined that 2,3,7,8-TCDD was present: (1) in the untreated leachate sampled at the Leachate Treatment Facility (but was not detected in the treated effluent); (2) in the sumps of certain ring 1 residences (sumps that also contained high concentrations of numerous other chlorinated organic compounds); and (3) in sediment samples collected from certain storm sewers that originated near the former canal, and in sediment samples collected from local creeks and the Niagara River near the outfalls of those storm sewers (sediments that also contained high concentrations of numerous other chlorinated organic compounds). These results for 2,3,7,8-TCDD at Love Canal both confirmed and extended the findings reported publicly in 1980 by NYS.

1.3 CONCLUSIONS

The results of the EPA multimedia environmental monitoring program conducted at Love Canal during the summer and fall of 1980 revealed a limited pattern of environmental contamination restricted mainly to the immediate vicinity of the inactive hazardous wastes landfill. The data suggested that localized and highly selective migration of toxic chemicals through soils had contaminated a few ring 1 houses located mainly south of Wheatfield Avenue. The data also revealed that substantial residual contamination was present in those local storm sewer lines originating near the former canal, and was also present in the surface water and sediment of area creeks and rivers at locations that were near to and downstream from the outfalls of those storm sewer lines.

Apart from these findings, the Declaration Area exhibited no clear evidence of Love Canal-related contamination in any environmental medium monitored. Also, in all media monitored, the data revealed that the occurrence and concentration levels of monitored substances observed in the Declaration Area could not be attributed in a consistent fashion to the migration of contaminants from Love Canal. The data also provided no evidence supporting the hypothesis that (outside of ring 1) swales may have served as preferential routes for chemicals to migrate from the former canal. Finally, the data suggested that the barrier drain system surrounding the landfill was operating effectively to intercept the lateral migration of contaminants from Love Canal, and was also drawing near-surface ground water back to the drains for collection and decontamination at the onsite Leachate Treatment Facility.

The patterns of environmental contamination discovered at Love Canal, that could be attributed directly to the migration of contaminants from Love Canal, were found to be consistent with the geology of the site. Because of the naturally occurring clayey soils in the general Love Canal area, the rapid and distant migration of substantial amounts of contaminants from the former canal to surrounding residences is highly unlikely. Migration of contaminants from Love Canal was found to have occurred over relatively short distances, probably through selective soil pathways consisting of more permeable materials, and was confined to ring 1 of the Canal Area. Even though the transport of contaminants was greater in the more permeable soils, the random deposition and apparent discontinuity of these soils made it highly doubtful that much contamination outside of ring 1 had occurred by ground-water transport.

CHAPTER 2
BACKGROUND

In order to understand the events leading to the May 21, 1980 emergency declaration order and to better understand the context in which the EPA Love Canal study was conducted, a brief review of the major historical developments pertaining to use of the Love Canal site is presented.

2.1 SITE LOCATION

The Love Canal Declaration Area is located in the southeastern portion of the La Salle section of the City of Niagara Falls, New York close to the corporate boundary of the Town of Wheatfield (Figure 1). The inactive hazardous wastes landfill known as Love Canal physically occupies the central 16-acre portion of the rectangular plot of ground bounded by Colvin Boulevard on the north, 99th Street on the east, Frontier Avenue on the south, and 97th Street on the west. Two roads, Read and Wheatfield Avenues, cross the landfill in an east-west direction. A public elementary school, known as the 99th Street Elementary School, occupies a portion of the land between Read and Wheatfield Avenues and was built adjacent to the eastern boundary of the landfill. The southernmost portion of the site is approximately 1,500 feet north of the Niagara River. Another inactive hazardous wastes site, known as the 102nd Street landfill, is located to the south of Love Canal and is approximately bounded by the following: Buffalo Avenue on the north; the Niagara River on the south; and lines that would be formed on the east by extending 102nd Street to the Niagara River, and on the west by extending 97th Street to the Niagara River.

The area encompassed by the May 21, 1980 state of emergency order, and the focus of the EPA Love Canal investigations, was the area previously identified as "DECLARATION AREA" in Figure 2 and referred to in this report as the Declaration Area. The area identified with the legend "CANAL AREA" in Figure 2 (referred to in this report as the Canal Area) depicts the location of the inactive landfill, and included nearly all of the houses that were acquired and evacuated by the State of New York in 1978. The boundaries of the Declaration Area corresponded roughly to the following streets and features identified in Figure 3: Bergholtz

Creek on the north; 102nd Street on the east (and its imaginary northward extension to Bergholtz Creek); 103rd Street on the southeast; Buffalo Avenue on the south; and 93rd Street on the west. The residences on the west side of 93rd Street and on the east side of 102nd and 103rd Streets were included in the state of emergency order and in the Declaration Area.

2.2 SITE HISTORY

In the early 1890's an entrepreneur named William T. Love envisioned the founding of a planned industrial community that he named Model City, to be located north of Niagara Falls in the present town of Lewiston, New York. Love's plan was to dig a canal diverting water from the Niagara River northward to the Niagara escarpment in order to economically produce hydroelectric power for the industries that Love hoped to lure to Model City. Work began on the canal on May 23, 1894 in the La Salle section of Niagara Falls. The canal was located in a 400-foot wide right-of-way and according to newspaper reports was to be 80 feet wide at the top, 30 feet deep, and 40 feet wide at the base. Apparently, due to the joint occurrence of a financial depression in the 1890's and the development of a practical means for generating alternating current by Nikola Tesla (1856-1943), which permitted the economical transmission of electrical power over long distances, Love's dream of Model City, fueled by the natural energy source of a power canal, soon evaporated.

While some uncertainty exists today as to both the originally excavated depth and the southernmost extension of the former canal that bears Love's name, it is known from aerial photographic evidence that in 1938 the portion of Love Canal bounded by Colvin Boulevard, 99th Street, Frontier Avenue, and 97th Street was open and filled to some depth with water. It is also known that excavated soils were piled near the edge of the canal, forming mounds estimated as 10 to 15 feet high in places.

In 1942 the company known today as Hooker Chemicals and Plastics Corporation (Hooker) entered into an agreement with the Niagara Power and Development Company (then owner of the canal) to purchase Love's unfinished canal. Although Hooker did not actually acquire the property until 1947, Hooker acknowledged that it used the canal between 1942 and 1953 for the disposal of at least 21,800 tons of various chemical wastes. A list of the types of wastes buried in Love Canal is presented in Table 3.

According to NYS interpretations of aerial photographs taken throughout the time period, Hooker apparently deposited chemical wastes in the canal by first constructing dikes across the canal, which formed impounded areas of water, and then filled the canal on a section-by-section basis. It is not known how much, if any, of the impounded water was drained from the canal prior to landfilling operations.

TABLE 3. CHEMICALS DISPOSED AT LOVE CANAL BY HOOKER ELECTROCHEMICAL COMPANY (1942-1953)†

Physical Type of Waste	State	Total Estimated Quantity (Tons)	Container
Misc. acid chlorides other than benzoyl--includes acetyl, caprylyl, butyryl, nitro benzoyls	liquid and solid	400	drum
Thionyl chloride and misc. sulfur/chlorine compounds	liquid and solid	500	drum
Misc. chlorination--includes waxes, oils, naphthalenes, aniline	liquid and solid	1,000	drum
Dodecyl (Lauryl, Lorol) mercaptans (DDM), chlorides and misc. organic sulfur compounds	liquid and solid	2,400	drum
Trichlorophenol (TCP)	liquid and solid	200	drum
Benzoyl chlorides and benzotrichlorides	liquid and solid	800	drum
Metal chlorides	solid	400	drum
Liquid disulfides (LDS/LDSN/BDS) and chlorotoluenes	liquid	700	drum
Hexachlorocyclohexane (γ-BHC/Lindane)	solid	6,900	drum and nonmetallic containers
Chlorobenzenes	liquid and solid	2,000	drum and nonmetallic containers
Benzylchlorides--includes benzyl chloride, benzyl alcohol, benzyl thiocyanate	solid	2,400	drum
Sodium sulfide/sulfhydrates	solid	2,000	drum
Misc. 10% of above		2,000	
Total		21,800	

---

†Interagency Task Force on Hazardous Wastes, Draft Report on Hazardous Waste Disposal in Erie and Niagara Counties, New York, March 1979. Hooker Electrochemical Company is now known as the Hooker Chemicals and Plastics Corporation.

The significance of the issue of whether or not water was drained from impounded areas prior to Hooker dumping wastes in the canal looms in potential importance when the topography of the site is considered. Although the general Love Canal area is quite flat, the region was traversed by a number of naturally occurring shallow (less than 10 feet deep) surface depressions, sometimes called swales, that served as preferential pathways of surface-water runoff. Some of the swales, which are now all filled, were intersected during excavation of the canal. The wavy lines superimposed on Figure 2 illustrate the approximate location of known former swales in the general vicinity of Love Canal.

It has been offered by others that Hooker's active landfilling operations may have displaced impounded water, potentially contaminated with toxic chemicals, into the drainage pathways. In addition, if the open swales were later filled with rubble and more permeable sandy-soils during residential constuction, then leachate may have preferentially migrated from the landfill through the filled swales to nearby houses. The EPA monitoring program was designed to test the validity of this hypothesis.

It is also known that the City of Niagara Falls disposed of solid wastes (mainly in the portion of the canal bounded today by Read and Wheatfield Avenues) in Love Canal. No other source of wastes disposed of in the canal has yet been identified.

Shortly after Hooker terminated disposal activities at Love Canal in 1953 the land was acquired for the purchase price of $1.00 by the Niagara Falls Board of Education for the purpose of constructing an elementary school on the site. In 1955 the 99th Street Elementary School, located adjacent to the eastern edge of the landfill on 99th Street between Read and Wheatfield Avenues, was completed and opened. A French drain system was installed around the school at the time of construction and was connected at some later time to a storm sewer line on 99th Street.

As early as 1938, a number of private residences were located near the northeast corner of Love Canal. By 1952 approximately 6 to 10 houses existed on 99th Street (the backyards of these houses faced toward the active dumping in the canal), mainly located around the central and south-central portions of the canal. By 1972 virtually all of the 99 houses on 97th and 99th Streets whose backyards faced the former canal, the so-called ring 1 houses, were completed. In general, residential development around Love Canal occurred primarily from the mid-1950's through the early 1970's. By 1966, all evidence of earlier excavation at the site had been eliminated by subsequent construction activities.

Shortly after the canal was filled in 1953, Read and Wheatfield Avenues were built across the landfill. Anecdotal reports by area residents relate that chemical wastes, fly ash, and municipal refuse were encountered during the construction of these streets. In 1957 the City of Niagara Falls installed a sanitary sewer line across the former canal under Wheatfield Avenue. The sewer pipe was laid approximately 10 feet below the surface of Wheatfield Avenue. Contrary to specification documents, which stipulated that the sewer pipe be encircled with gravel, field inspection notes compiled by the State of New York Department of Environmental Conservation (NYS DEC) reported that only excavated soils were used to backfill the trench.

In 1960 the City of Niagara Falls installed a storm sewer line under Read Avenue, entering from 97th Street and ending in a catch basin located approximately midway between 97th and 99th Streets. Field inspection notes (NYS DEC) once again reported that only excavated soils were used to fill the trench. Although city records do not identify the construction of storm sewer laterals on Wheatfield Avenue, connecting to storm sewer lines on 97th and 99th Streets, field inspection notes (NYS DEC) reported that storm sewer laterals were built at some time on Wheatfield Avenue entering from both 97th and 99th Streets and each running towards the former canal for approximately 170 feet. As with other sewer lines installed by the City of Niagara Falls around Love Canal, these too were reportedly (NYS DEC) backfilled with excavated soils.

As early as 1966 a little league baseball diamond was located on the northern portion of Love Canal just south of Colvin Boulevard. In 1968 the La Salle Expressway was constructed north of Buffalo Avenue. The construction of this four-lane divided highway required the relocation of Frontier Avenue approximately 50 feet northward. During the relocation of Frontier Avenue, chemically-contaminated soils and drummed wastes were encountered. At the request of the State of New York Department of Transportation (DOT), Hooker agreed to remove 40 truckloads of wastes and soil. At the same time that Frontier Avenue was relocated, the storm sewer line under Frontier Avenue was also relocated by DOT. Field inspection notes (NYS DEC) reported that the storm sewer line installed by DOT was constructed according to specifications and encircled with gravel prior to backfilling the excavation trench.

As a result of unusually high precipitation in 1975 and 1976, a very high ground-water level apparently developed in the general Love Canal area. At about this time a number of problems became markedly noticed by Love Canal residents, namely: (1) portions of the landfill subsided and drums surfaced in a number of locations; (2) ponded surface water, heavily contaminated with chemicals, was found in the backyards of some ring 1 houses; (3) unpleasant chemical odors (caused by the volatilization of surfaced chemical wastes) were cited by residents as a factor contributing to both discomfort and illnesses; (4) evidence of through-ground migration of toxic chemicals became apparent in the basements of some ring 1 houses with the appearance of a noxious, oily residue accumulating in basement sumps, the corrosion of sump pumps, and the physical evidence of chemical infiltration through cinder-block foundations; and (5) noxious chemical fumes were noticed emanating from several near-by storm sewer manhole covers.

By November of 1976, the frequency and magnitude of the problems at Love Canal cited by area residents prompted a meeting of local, state, and federal officials where it was agreed that NYS DEC would conduct and be responsible for an investigation of the site, and that EPA would provide technical assistance. During the subsequent year, a number of environmental samples were collected in ring 1 houses and at the 99th Street Elementary School.

Partially as a result of these investigations, Commissioner Robert P. Whalen of the State of New York Department of Health (DOH) in April of 1978 declared the site to be a threat to health and ordered that the area nearest the landfill be fenced. In June 1978 NYS DOH initiated a house-to-house health survey and collected air samples in ring 1 houses. After reviewing all available Love Canal data, Commissioner Whalen declared a health emergency at Love Canal on August 2, 1978. The order issued by Whalen resulted in, among other things, the closing of the 99th Street Elementary School and a recommendation for the temporary evacuation of pregnant women and all children under the age of 2 who resided in the first two rings of houses around the former canal.

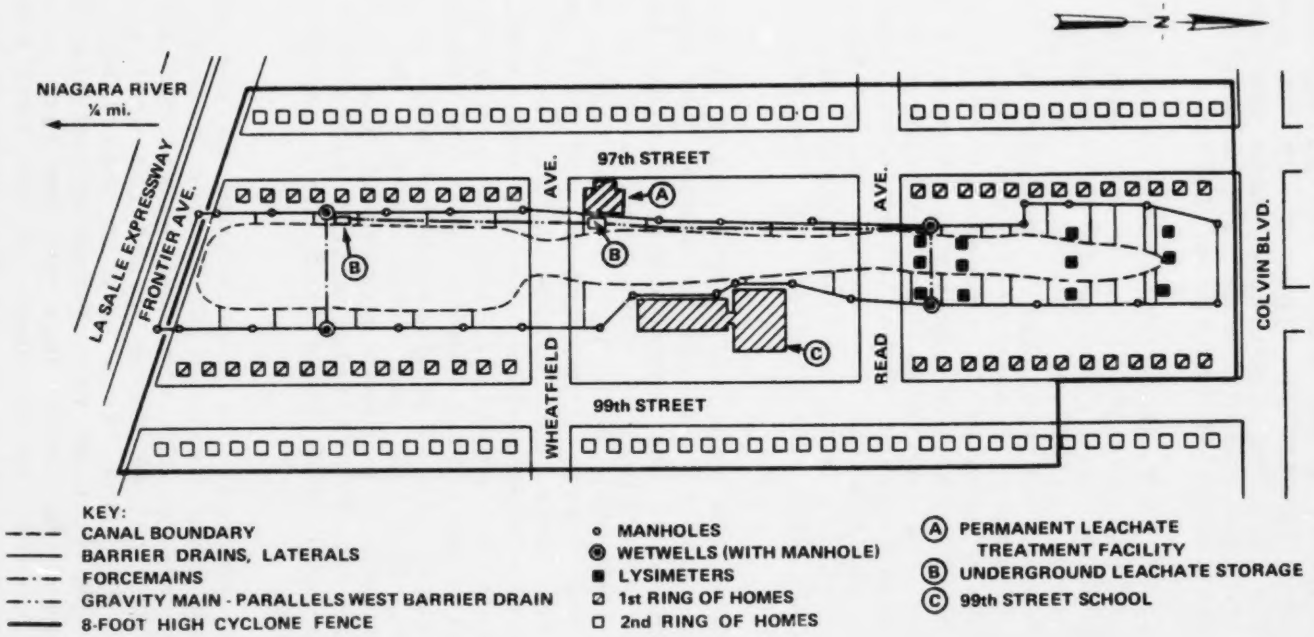
On August 7, 1978 Governor Carey announced that NYS would purchase (at full replacement value) all ring 1 houses at Love Canal. This announcement of the permanent relocation of Love Canal residents was subsequently expanded to include all 238 rings 1 and 2 houses. On the same date, President Carter issued an order declaring that a state of emergency existed in the southern portion of Love Canal, where contamination was at its worst level, enabling the use of federal funds and the Federal Disaster Assistance Agency to aid the City of Niagara Falls in providing remedies at the site.

During the latter part of 1978 and through the spring of 1979 the City of Niagara Falls (partly with the aid of federal funds) designed and constructed a barrier drain system parallel to, and on both sides of, the southern portion of Love Canal. The barrier drain system installed by the City of Niagara Falls was essentially a French drain containing perforated tile-pipe. The perforated tiles were buried in a trench 12 to 15 feet in depth, covered with 2 feet of uniformly sized gravel, and then backfilled with sand. Initially, leachate collected from the landfill was treated onsite by an EPA mobile activated-carbon filter system. Subsequently, a permanent activated-carbon Leachate Treatment Facility (partially financed by an EPA cooperative agreement with NYS DEC) was constructed near the northeast corner of 97th Street and Wheatfield Avenue. The Leachate Treatment Facility became operational at the end of 1979.

In the spring of 1979, NYS DEC assumed responsibility for the construction of additional portions of the barrier drain system in the central and northern sections of Love Canal. The portions of the barrier drain system constructed by DEC were connected to the southern system, and included a complete encircling of the former canal in the north (south of Colvin Boulevard) and in the south (approximately located in the center of Frontier Avenue). In the north, the drains were located in trenches up to 18 feet in depth. Figure 5 illustrates the approximate location of the entire barrier drain system installed at Love Canal by the City of Niagara Falls and NYS DEC. The entire DEC project was completed by the end of 1979, with contract costs totalling more than $13 million (including construction of the Leachate Treatment Facility).

The purposes of the remedial construction at Love Canal were many. First, a leachate collection system was installed around the entire perimeter of the former canal in order to prevent continuing lateral migration of contaminants from the landfill. Second, lateral trenches were dug from the main barrier drain trench towards the former canal and filled with sand to hasten dewatering of the site and to facilitate construction. And third, a relatively impermeable clay cap was installed over the landfill to minimize volatilization of contaminants, prevent human contact with hazardous wastes, prevent runoff of contaminated surface water, and to minimize the amount of precipitation infiltrating the landfill and thus reduce the generation of leachate. In Figure 6 a cross section of the former canal and the barrier drain system are illustrated, along with an identification of the general soil units (and their permeabilities) that exist in the area.

It should be pointed out that access to the Canal Area and the landfill has been restricted to the general public since 1979. Public access to the site was eliminated by the erection of an 8-foot high cyclone fence around the entire area; for security purposes, the Canal Area is also patrolled. In Figure 5, the approximate location of this fence around the site was identified. The reason the fence does not restrict access to all of 99th Street is due to the presence of two families (as of February 1982) who still reside on the east side of 99th Street, and have declined to sell their homes to the State.


N
NIAGARA RIVER
¼ mi.
LA SALLE EXPRESSWAY
FRONTIER AVE.
97th STREET
99th STREET
WHEATFIELD
AVE.
READ
AVE.
COLVIN BLVD.
A
B
B
C
KEY:
CANAL BOUNDARY
BARRIER DRAINS, LATERALS
FORCEMAINS
GRAVITY MAIN - PARALLELS WEST BARRIER DRAIN
8-FOOT HIGH CYCLONE FENCE
MANHOLES
WETWELLS (WITH MANHOLE)
LYSIMETERS
1st RING OF HOMES
2nd RING OF HOMES
Ⓐ PERMANENT LEACHATE TREATMENT FACILITY
Ⓑ UNDERGROUND LEACHATE STORAGE
Ⓒ 99th STREET SCHOOL

(ADAPTED FROM A FIGURE PREPARED BY THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION. USED BY PERMISSION)

Figure 5. Love Canal Remedial Action Project Plan View (not to scale).

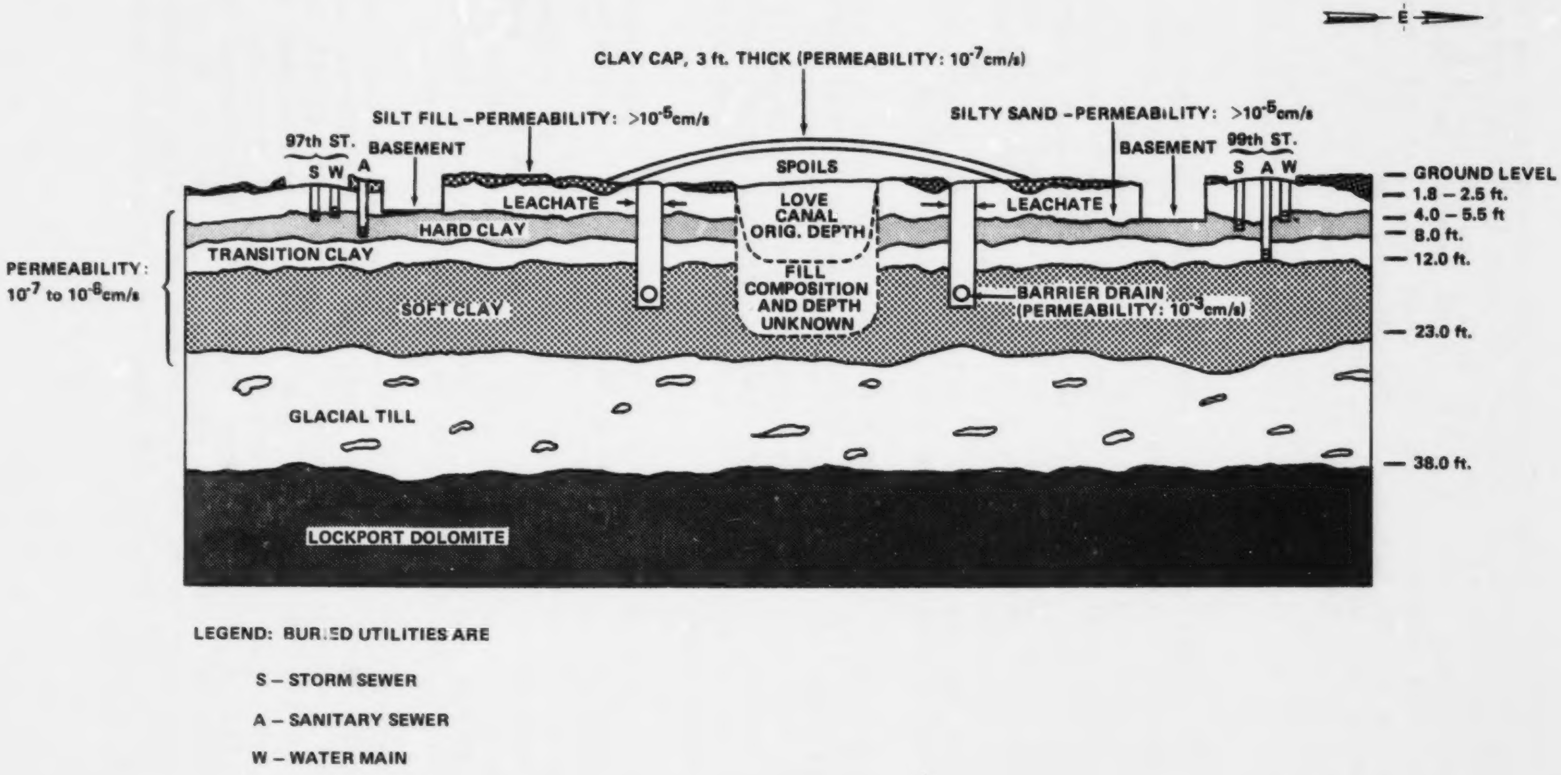

E
CLAY CAP, 3 ft. THICK (PERMEABILITY: 10⁻⁷cm/s)
SILT FILL - PERMEABILITY: >10⁻⁵cm/s
SILTY SAND - PERMEABILITY: >10⁻⁵cm/s
97th ST.
S W A
BASEMENT
BASEMENT
99th ST.
S A W
SPOILS
LEACHATE
LEACHATE
LOVE CANAL ORIG. DEPTH
FILL COMPOSITION AND DEPTH UNKNOWN
HARD CLAY
TRANSITION CLAY
SOFT CLAY
BARRIER DRAIN (PERMEABILITY: 10⁻³cm/s)
PERMEABILITY: 10⁻⁷ to 10⁻⁶cm/s
GLACIAL TILL
LOCKPORT DOLOMITE
GROUND LEVEL
1.8 – 2.5 ft.
4.0 – 5.5 ft
8.0 ft.
12.0 ft.
23.0 ft.
38.0 ft.
LEGEND: BURIED UTILITIES ARE
S – STORM SEWER
A – SANITARY SEWER
W – WATER MAIN

Figure 6. Remedial Project: Transverse View (Looking North from a Position Located South of Wheatfield Avenue).

During remedial construction the encountering of buried wastes in the northwestern portion of the landfill necessitated a westward extension of the barrier drain system on the 97th Street side of the former canal between Read Avenue and Colvin Boulevard. During the construction of that portion of the barrier drain system a catch basin was discovered near the former canal boundary, along the property line between 949 and 953 97th Street that had been installed by the City of Niagara Falls for the purpose of draining the immediate area. The catch basin was found to be connected to the 97th Street northward flowing storm sewer line.

During the construction of the southern portion of the barrier drain system three separate pieces of field tiles were discovered. It was offered by local residents that at one time these tiles were used to drain some property (or properties) east of the site into the canal. These field tiles were documented in NYS DOH field inspection notes as being located near the following lots: 454 99th Street; north side of 474 99th Street; and on the lot line between 474 and 476 99th Street. Both the catch basin on 97th Street and the field tiles on 99th Street were cut-off by installation of the barrier drain system.

After a yearlong investigation, the Department of Justice, on behalf of EPA, filed a civil lawsuit against Hooker (and related corporate defendents) on December 20, 1979 for improper hazardous waste disposal at four Niagara Falls sites. The lawsuit alleged, among other things, that Hooker had caused or contributed to the creation of an "imminent and substantial endangerment" and a nuisance at Love Canal.

In January 1980 EPA, at the request of the Department of Justice, contracted for a limited pilot cytogenetic assessment of 36 Love Canal residents for evidence-gathering purposes. The intent of the study was twofold: first, to determine if excess chromosome damage was present among Love Canal residents; and second, to determine if the prevalence and severity of cytogenetic abnormalities detected warranted a full-scale investigation. On May 19, 1980 the results of the assessment were released.

From a scientific point of view, the EPA pilot cytogenetic assessment suggested that the testing of additional Love Canal residents was probably warranted. However, a great amount of uncertainty as to the cause of the observed chromosomal abnormalities remained. In particular, the lack of physical evidence attributing (in a dose-response fashion) cytogenetic damage to incremental exposure to toxic chemicals migrating directly from Love Canal left the cause of the observed damage unknown. In addition, the personal health implications resulting from damaged chromosomes remained unknown.

Partially as a result of these events President Carter declared on May 21, 1980 (for the second time) that a state of emergency existed at Love Canal. This action led to the temporary relocation of those residents desirous of moving and to the initiation of the EPA Love Canal environmental monitoring studies described in this report. On June 10, 1980 EPA officials from the Office of Monitoring Systems and Quality Assurance (OMSQA), went to Love Canal to outline to area residents the nature of the environmental monitoring studies that EPA planned to conduct. EPA field sampling activities at Love Canal began on August 8, 1980 and were concluded on October 31, 1980.

As was mentioned earlier, on October 1, 1980 a plan for the permanent relocation of all desirous Love Canal emergency declaration area residents was announced. This plan implemented the Supplemental Appropriations and Rescission Act of 1980 (commonly known as the Javits-Moynihan amendment), 94 Stat. 857, that authorized the federal government to provide up to $15 million financial assistance to the State of New York for the permanent relocation of residents living in the Declaration Area. Partially as a result of this agreement an Agency of the State of New York, the Love Canal Area Revitalization Agency (LCARA), under the leadership of Mayor Michael C. O'Laughlin of Niagara Falls, assumed the responsibility for acquiring the property of those residents who desired to sell their property, and for relocating renters in the La Salle Development and senior citizens area. In addition, LCARA was given the responsibility for long term planning and revitalization of the general Love Canal area.

CHAPTER 3
DESIGN OF THE MONITORING STUDIES

The environmental studies initiated by EPA at Love Canal were designed as an integrated multimedia (that is, air, soil, sediment, water, and biota) monitoring program to characterize the incremental extent and degree of chemical contamination in the May 21, 1980 emergency declaration area directly attributable to the migration of contaminants from the former canal. The use of a multimedia data collection strategy was intended to permit the evaluation of the importance of each of the media pathways (environmental routes) through which individuals might be exposed to toxic substances, and permit an eventual assessment of total incremental exposure.

3.1 OBJECTIVES

The general objectives of the multimedia study designed and conducted by EPA at Love Canal were as follows:

1. To characterize in each medium sampled the incremental extent and degree of environmental contamination in the Declaration Area directly attributable to Love Canal.

2. To determine the presence and direction of ground-water flow in the area, and evaluate the effectiveness of the remedial construction performed at Love Canal.

3. To determine if swales, sewer lines, and other geological features (for example, sandy soil deposits in the form of sand lenses) had a significant effect on the migration of toxic substances from the former canal.

4. To obtain measurements of environmental contamination.

5. To determine potential temporal variability in air contamination levels and infer the causal mechanisms (for example, changes in ambient temperature) influencing the observed contamination patterns.

6. To investigate the use of locally available biological systems as potential indicators of contaminants present in the environment.

7. To provide an assessment of the relative environmental quality of the Love Canal emergency declaration area.

3.2 IMPLEMENTATION

The EPA studies were initiated by first identifying the data requirements of the overall objectives and then designing data collection mechanisms appropriate for such activities. Within the overall limitations of time, budget, and feasibility, a multimedia monitoring program was designed and implemented at Love Canal. As was previously mentioned, the contract costs associated with the Love Canal project were $5.4 million. GCA Corporation of Bedford, Massachusetts was selected as the prime management contractor. Other subcontractors involved in the study, and their areas of involvement, are identified in Table 4. The EPA National Enforcement Investigations Center (Denver, Colorado) provided assistance and guidance to sampling personnel in health and safety related matters during the collection of field samples.

As was mentioned previously, the identification of chemicals to be determined in field samples was accomplished by reviewing all available data concerning the contents of the landfill, including: (1) reviewing the list of chemical wastes that Hooker reported to have buried in Love Canal (Table 3); (2) reviewing the results of all known previous environmental monitoring studies performed at Love Canal (including those conducted by both NYS DOH and EPA); and (3) through the analysis of air, liquid, and sediment samples collected by EPA directly from the Leachate Treatment Facility and directly from the barrier drain system at Love Canal, prior to the initiation of EPA field sampling activities. As a result of these efforts, comprehensive lists of substances to monitor in water/soil/sediment/biota samples and in air samples were derived. The two lists are presented in Appendix A of this Volume.

At the outset of the monitoring program it was postulated that chemicals in the former canal were likely to have selectively migrated from the source according to environmental medium and according to location in the landfill (due to highly heterogeneous soil conditions at the site), and in concentration levels that decreased with increasing distance from Love Canal. In addition, it was also recognized: (1) that former swales may have preferentially allowed the migration of chemicals from the site (due to the possibility that materials used to fill the swales had greater permeability than the surrounding natural soils); (2) that residences located in historically wet areas (that is, with

TABLE 4. IDENTIFICATION OF EPA LABORATORIES AND PROJECT SUBCONTRACTORS

EPA Laboratories

Laboratory (Abbreviation)	Activity
Environmental Monitoring and Support Laboratory, Cincinnati (EMSL-Cin)	QA/QC for water samples; audit of gas chromatography/mass spectrometry (GC/MS) subcontractor analyses
Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV)	Water monitoring; soil/sediment/biota monitoring and QA/QC; audit of GC/MS subcontractor analyses
Environmental Monitoring Systems Laboratory, Research Triangle Park (EMSL-RTP)	Air monitoring and QA/QC for air samples; contract supervision; data processing
Environmental Research Laboratory, Ada (ERL-Ada)	Hydrogeologic program
Environmental Research Laboratory, Athens (ERL-Athens)	Audit of GC/MS subcontractor analyses
Environmental Research Laboratory, Corvalis (ERL-Corvalis)	Analysis of selected samples
Environmental Research Laboratory, Duluth (ERL-Duluth)	Analysis of selected samples
Health Effects Research Laboratory, Research Triangle Park (HERL-RTP)	QA/QC for PFOAM samples; confirmation of TCDD results

Analytical Subcontractor Laboratories

Laboratory (Abbreviation)	Type of Analysis
Acurex Corporation (ACEE)	Organics in soil, sediment, and water
Advanced Environmental Systems, Inc. (AES)	TOX and TOC
Battelle Columbus Laboratories (BCL, BCL2, BCL3)	Air volatile organics
Compuchem/Mead Technology Laboratories (CMTL)	Organics in soil, sediment, and water

(continued)

TABLE 4 (continued)

Analytical Subcontractor Laboratories

Laboratory (Abbreviation)	Type of Analysis
Energy Resources Company (ERCO)	Inorganics in soil, sediment, and water
Gulf South Research Institute (GSRI, GSLA, GSNO)	Air semi-volatile organics; organics in soil, sediment, and water
IIT Research Institute (IIT)	Air volatile organics
Midwest Research Institute (MWRI)	Organics in biota
PEDCo Environmental (PEDC)	Air volatile organics; preparation of TENAX cartridges
PJB/Jacobs Engineering Group (PJBL)	Organics in soil, sediment, and water; inorganics in soil, sediment, and water
Southwest Research Institute (SWRI)	Air semi-volatile organics; organics in biota, soil, sediment, and water; inorganics in biota, soil, and sediment; preparation of polyurethane foam plugs
TRW, Inc. (TRW)	Organics in water
Wright State University (WSU)	TCDD (Dioxin) determinations

Other Subcontractors

Organization	Activity
Empire Soils	Well drilling
Geomet Technologies	Field sample collection
GeoTrans	Ground-water modeling
JRB	Supervisory geologists
Research Triangle Institute	Provision of quality control TENAX cartridges
Technos	Geophysical investigation

standing surface-water problems) were also typically associated with the presence of former swales; (3) that local creeks and rivers may be contaminated and serve as additional sources of human exposure; (4) that manmade construction activities (such as streets and utilities buried therein) may have had a major influence on the subsurface migration of toxic substances from the former canal; and (5) that efficiency in statistically estimating typical chemical concentration levels, and the mapping of concentration isopleths in certain media, could be enhanced through stratification of the Declaration Area into more compact sampling areas (in order to increase intra-area environmental homogeneity).

With these considerations in mind, the sampling area scheme described previously, and schematically represented in Figure 4, was superimposed on the Declaration Area. Within each sampling area, for a variety of media, site selection occurred by both simple random selection (that is, with equal probability), and purposive selection. At nine residences, referred to as base sites, extensive integrated multimedia environmental monitoring was conducted. The purposive selection of sampling sites was conducted with the intent of increasing the likelihood of detecting transport pathways through which toxic contaminants may have migrated into the Declaration Area from Love Canal.

It can be seen in Figure 4 that the distribution and location of sampling areas around the Canal Area (area 11) was designed to facilitate the estimation of concentration isopleths. In addition, it can be seen that nearly all sampling area boundaries were coincident with existing physical boundaries, and that proximity of residences to area creeks was also incorporated in the design (area 4). In subsequent figures identifying media specific sampling locations, it will be apparent to the reader that (for relevant media) sites were often intentionally selected to permit monitoring of former swales located throughout the area.

Efforts were made for all monitored medium/source/location combinations to obtain control sampling sites that were selected specifically for comparison purposes. As a matter of convenience all control sites data were collected in one organizational sampling area, area 99, and are reported in this fashion in Volumes II and III of this report. It should be noted that the control sites do not really represent a physically bounded area, but rather are simply a collection of medium-specific sampling sites. Due to the physical distance separating control sampling sites, no specific control area could be identified in Figure 4. Whenever possible, control sites are identified and included in subsequent figures showing medium-specific sampling locations.

Special attention was given to selecting control site locations in the Niagara Falls area that were not influenced directly by Love Canal or any other known hazardous waste sites. The control sites were monitored to determine normal pollutant levels found near to (but not influenced by) Love Canal. The relative concentration differences found between the Declaration Area and other areas of interest were determined by subtraction.

As was mentioned earlier, EPA responded to the requests of local residents living outside the Declaration Area to collect additional environmental samples. The results from these sampling efforts were combined (in Volumes II and III) in one organizational sampling area, area 97. Also included in Volumes II and III are data for sampling area 98. The data included in this sampling area were obtained as part of the previously mentioned ambient-air transport monitoring study, which was conducted to determine the nature and amount of pollutants being transported to the Declaration Area from sources other than Love Canal.

3.3 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC) AND DATA VALIDATION

Because QA/QC procedures form an integral part of any assessment of the appropriateness and utility of the Love Canal data, a brief discussion of certain QA/QC concepts, processes, and results is presented here. A more detailed discussion of medium-specific QA/QC procedures and results may be found in Appendixes C through E of this Volume. In addition, a comprehensive report entitled Love Canal Monitoring Program, GCA QA/QC Summary Report, describing the QA role and activities of the prime contractor (GCA Corporation), may be obtained from the National Technical Information Service (NTIS).

In response to the presidential order declaring a state of emergency at Love Canal, and the great anxiety experienced by local residents associated with this action, the monitoring program devised by EPA was restricted to a 3-month sampling period. Given this sampling-period time constraint, necessary cost contraints, and a directive to determine the extent and degree of environmental contamination in the Declaration Area directly attributable to the migration of contaminants from Love Canal, comprehensive medium-specific sampling designs were developed. The major objective of the survey design was to collect and analyze a statistically adequate number of samples to characterize accurately Declaration Area contamination caused by Love Canal, and to minimize the effects and uncertainties associated with the constrained sampling time period. The analytical requirements established by EPA were designed to complement the extensive sampling programs. This was accomplished by targeting (using the process described earlier) a relatively large number of substances to be determined in environmental samples. As a result of these efforts, the likelihood was minimized that substantial evidence of environmental contamination would be missed in the Declaration Area samples collected.

Given these general program requirements, analytical methods were selected such that the following considerations were satisfied. First, the shortness of the sampling time period (3 months), and the magnitude of the sampling program (more than 6,000 field samples were collected), necessitated the use of a large number of analytical subcontractors. Typically, the quantity of samples collected at Love Canal required that more than one analytical subcontractor laboratory be used for each medium sampled.

Second, the relatively large number of targeted organic compounds to be determined in environmental samples, and the number of analytical subcontractors needed to analyze the samples collected, required the use of uniform analytical methods that had the capacity for rapid sequential analysis of the large number of organic compounds of interest at Love Canal.

Third, potential problems resulting from the organic analytical requirements of the program were minimized by selecting (whenever possible) already existing analytical methods, in order to take advantage of any prior experience that the subcontractors may have had with the methods.

Fourth, the state of emergency at Love Canal precluded any opportunity for formal multilaboratory testing of certain state-of-the-art organic analytical methods selected for use during the project.

Finally, in recognition of these factors, a primary goal of qualitative accuracy for organic analyses (that is, correct identification of detected substances) was established. Consequently, gas chromatographic/mass spectrometric (GC/MS) instrumentation was selected for most organic analyses because it most completely and reliably met the aforementioned requirements for the analysis of targeted organic compounds in water, soil, sediment, and air samples.

Given the constraints just enumerated, the primary objective of the EPA Love Canal QA/QC program was to generate environmental monitoring data that possessed the maximum accuracy, precision, and specificity attainable. In order to achieve these objectives, the QA/QC program developed by EPA consisted of the following components (additional detailed documentation may be found in the previously mentioned GCA Corporation report Quality Assurance Plan, Love Canal Study, LC-1-619-206, available from NTIS).

First, internal QC programs were specified by EPA for use at each of the analytical subcontractor laboratories. The QC programs required by EPA established minimally acceptable standards that all subcontractors satisfied. Many subcontractors adopted more stringent QC programs that were approved by EPA.

Second, the prime contractor (GCA Corporation) managed the day-to-day quality assurance program, which provided continuing and immediate oversight of all subcontractors, and timely identification and correction of sampling and analytical problems (details regarding the results of this program may be found in Love Canal Monitoring Program, GCA QA/QC Summary Report). The QA program that the GCA Corporation managed was devised by EPA and included the following components:

1. Requirements for sample collection, preservation, and holding times
2. Requirements for on-site sampling systems audits and personnel performance audits
3. Requirements for analytical methods, calibrations, and control chart usage
4. Requirements for external analytical QA programs, including the use of EPA performance evaluation and quality control samples
5. Requirements for internal analytical QA programs, including the measurement of reference compounds, method blanks, laboratory control standards, laboratory duplicates, and surrogates or target compound spikes. Requirements for spiking concentrations, laboratory control standards, and control limits were stipulated for some methods.
6. Requirements for the collection and analysis of a specified number of replicate field samples and field blanks
7. Requirements for splitting field samples between laboratories
8. Precision and accuracy goals were specified as appropriate.

Third, EPA performed an intentionally redundant retrospective evaluation of the QA/QC program, which involved reviewing all of the analytical data generated by the subcontractors, and validating those portions of the monitoring data satisfying EPA standards (details of this process are presented in Appendixes C through E of this Volume). Briefly, the process of validating data involved the purposeful rejection of certain analytical results whenever compelling QA/QC evidence was present that identified the occurrence of errors in sampling, preservation, or analytical method execution which were associated with those results. No other data (such as statistical "outliers") were eliminated from the Love Canal data base. Volume II contains a listing of all validated Love Canal data.

Finally, because many of the analytical methods employed for medium-specific organic analyses were state-of-the-art procedures not yet formally (multilaboratory) tested, the comprehensive QA/QC procedures employed were designed to permit, as appropriate, estimation of the precision and accuracy of these methods by EPA. The basis for such estimation was through the acquisition and analysis of QA specific duplicate and triplicate field samples at Love Canal, and the analysis of well-characterized external QC samples (that is, specially prepared samples whose analytes and concentration levels were unknown to the analytical subcontractors) and internal QC samples. Procedures employed for these purposes are described in the GCA Corporation document Quality Assurance Plan, Love Canal Study, LC-1-619-206.

As used here, the term "accuracy" includes both qualitative accuracy, the ability of a measuring system to correctly identify the presence or absence of a particular analyte in a sample when the analyte is actually present or absent, and quantitative accuracy, the ability of a measuring system to specify the amount of an analyte present in a particular sample. The term "precision" refers to the amount of variability (that is, the likely range of values that would be observed in identically repeated measurements) associated with any one particular measurement value.

In order to determine the presence and concentration levels of the relatively large number of targeted substances (presented in Tables A-1 and A-2 of Appendix A) to be determined in Love Canal samples, an extensive, detailed set of procedures (protocols) were established that stipulated the exact manner in which all sampling and analytical activities were to be conducted. Even though the protocols used served to standardize all such activities, it must be recognized that the numerous complex actions required, and the sophisticated instrumentation employed, resulted in a certain amount of unavoidable variability in the application of measurement system methodologies. Knowledge about the variability inherent in all environmental measurement systems becomes increasingly important as the concentration of the analyte(s) of interest in a sample decreases. Consequently, for low-level (sometimes called "trace") environmental measurements, it is essential that the variability of the measurement systems used be known (or be estimated), in order to understand the confidence that can be associated with any one particular measurement value. The establishment of appropriate QA/QC procedures was designed to document fully the process by which the Love Canal monitoring data were generated, and to provide some indication of measurement systems variability. The reader interested in additional detailed information on the QA/QC programs used at Love Canal, and the results of these efforts, should consult Appendixes C through E of this Volume, and the previously mentioned GCA Corporation reports available from NTIS.

Before concluding this section, it should be pointed out that a comprehensive QA/QC effort was conducted by EPA at Love Canal. As a result, the Love Canal data are carefully validated environmental measurements, and (given the constraints previously mentioned) are representative of the current state-of-the-art in environmental measurement methodology in terms of precision, accuracy, and specificity.

3.3.1 Limits of Detection and Quantitation

The measurement of low-level ("trace") amounts of organic compounds in environmental samples is a challenging task for the analytical chemist. Because of the inherent uncertainties associated with such efforts, it has become common practice to require that a certain concentration level of a compound be present in a sample before an analyst will assert that the compound is actually present. The smallest amount of a compound recognized as measurable in a sample (with a given finite probability) is called the limit of detection (LOD). The LOD varies from one compound to another, from one sample matrix to another, from one measurement system to another, and can vary in the same measurement system from one determination to the next.

A concentration level somewhat higher than the LOD should be established whenever applicable as the level at which the concentration of a compound present in a sample (with a given finite probability) will be quantified. This concentration level of a compound in a sample is referred to as the limit of quantitation (LOQ). Concentration levels of compounds in the interval LOD to LOQ are often, by convention, called "trace" values of the compounds. The LOQ also varies from one compound to another, from one sample matrix to another, from one measurement system to another, and can vary on the same measurement system from one determination to the next. Statistical analyses of the monitoring data generated from Love Canal field samples treated all "trace" concentrations of compounds as positive occurrences (that is, detections) of those compounds in samples analyzed. Appendixes C through E (in the sections entitled "Limits of Detection/Quantitation") contain additional details on LOD and LOQ, and present tables indicating LOD values for certain monitored substances.

3.3.2 Precision and Accuracy Goals

For the analysis of organic compounds in all media, a primary goal of maximizing specificity (that is, maximizing the probability of correct compound identification) was established at the initiation of the study. The approach selected to achieve this goal was through the application of chromatographic methods that use a mass spectrometer (MS) detector. In these methods, the mass spectrometer was required to be operated in the repetitive scanning mode. Compound identification criteria were provided that employed both relative chromatographic retention time information and mass spectra data. The only exceptions to this approach to qualitative accuracy involved determinations of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), and a few pesticides at below parts per billion levels. For 2,3,7,8-TCDD determinations, which were measured at concentrations as low as 10 parts per trillion, the highly specific approach of high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) with selected ion monitoring was used. For certain pesticides determinations, which were measured at various low parts per trillion levels, gas chromatography with an electron capture detector (GC/ECD) was used. In addition, confirmation of pesticide identification by GC/MS was required, whenever concentrations permitted, to minimize false-positive identifications.

The requirement for complete spectra acquisition to assure high qualitative accuracy in compound identification placed a major constraint on the precision of concentration measurements, and on method detection and quantitation limit goals. For example, it is known (P. Olynyk, W. L. Budde, and J. W. Eichelberger, J. Chromatographic Science, 1981, 19, 377) that in water, the acceptable total method precisions expected for one of the methods used are in the relative standard deviation (RSD) range of 2 to 13 percent, depending on the analyte. Precisions better than this were neither required nor expected of the analytical subcontractors. Precisions better than 50 percent RSD were expected in water and air; precisions better than 100 percent were expected in the other media. Furthermore, it is also known (J. A. Glaser, D. L. Foerst, G. D. McKee, S. A. Quave, and W. L. Budde, Environmental Science and Technology, 1981, 1426) that in water, the minimum method quantitation limits expected for the methods used are in the range of 1 to 10 micrograms per liter (parts per billion), depending on the analyte; minimum method quantitation limits were estimated for other methods and are reported in Appendixes D and E. Quantitation limits below these values were neither required nor expected of the analytical subcontractors, except as noted previously for 2,3,7,8-TCDD and certain pesticides.

For metals analytes, highly reliable methods based on absorption and emission spectrometries were selected to assure high qualitative accuracy in element identification. Precision and method quantitation goals were of the same order of magnitude as those described for the organic analytes.

The precision and accuracy of the monitoring data obtained from Love Canal are documented in Appendixes C through E, in the sections entitled "Estimates of Data Precision" and "Estimates of Data Accuracy."

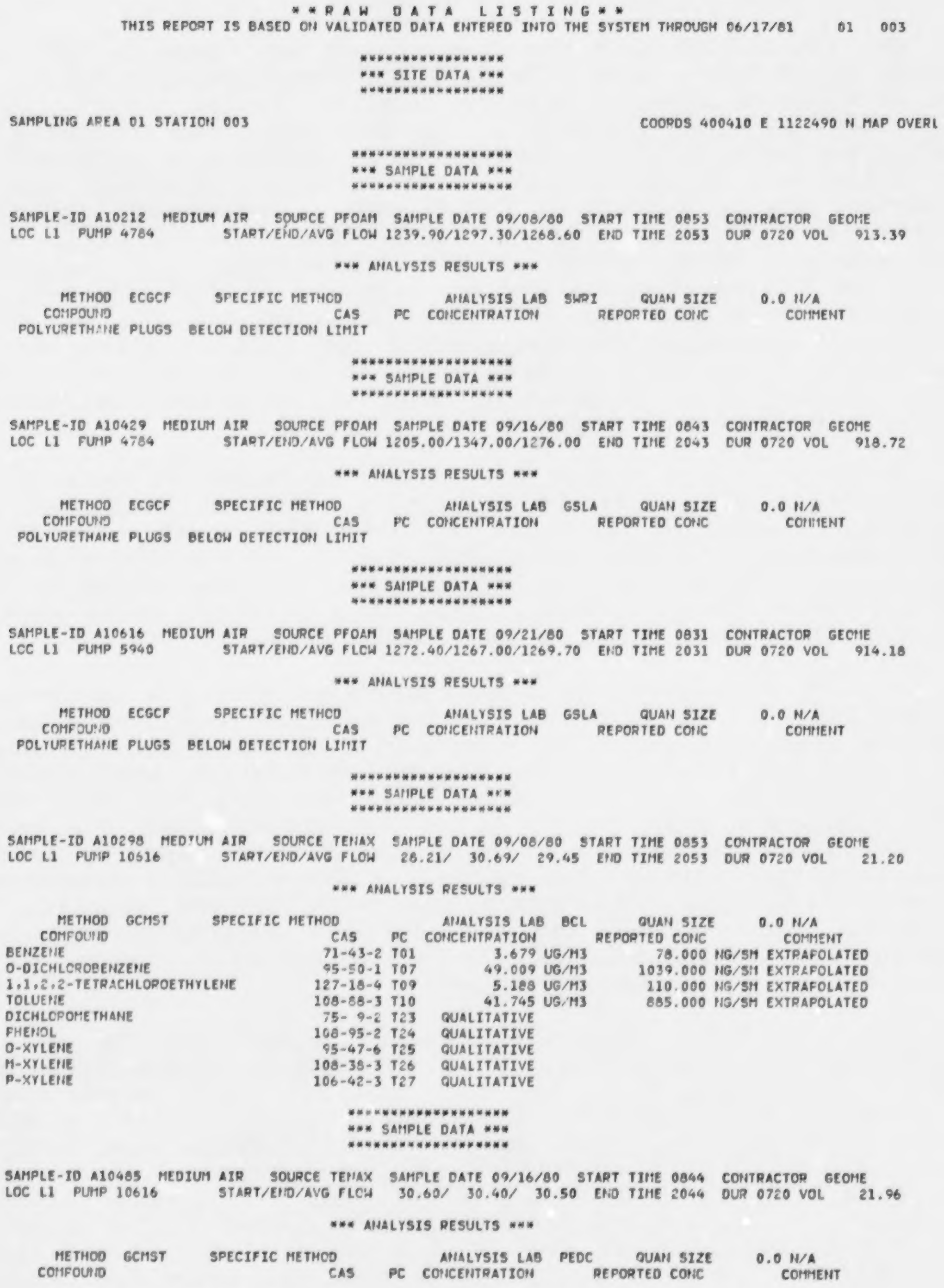
3.4 DATA ANALYSIS AND DATA REPORTING

The entire EPA Love Canal validated data base is listed in Volume II of this report. The data are organized by sampling area and within each sampling area by sampling station (site). Within each sampling site, the data are further organized according to a medium/source/location taxonomy that facilitates reference to particular collections of data. (See Table 2). For each analysis reported, a wide variety of information is presented, including: sample identification number; medium (for example, air); source (for example, TENAX, PFOAM, or HIVOL); location (for example, L1 or L2 for living area, BA for basement, or O1 for outside); date on which the sample was collected; time of day the sample was collected; subcontractor responsible for sample collection; and analysis information including analysis method, analysis laboratory, sample size, substances detected, and the corresponding concentration of the substance in the sample.

In Figure 7, a sample page from the validated data listing contained in Volume II is presented. Due to confidentiality agreements, sampling locations are identified in this report only by unique sampling area and station codes. In subsequent figures, the approximate location of medium-specific sites in the vicinity of the Declaration and Canal Areas is indicated, along with the corresponding sampling area and station code.

Statistical summaries of the validated data are collected in Volume III of this report. For the sake of consistency in presenting data, the summaries constructed involved aggregating the data by both sampling area, and by Declaration Area (sampling areas 1 through 10), Canal Area (sampling area 11), and Control Area (sampling area 99). It is recognized that for certain medium/source combinations, the aggregation of data by sampling area is inappropriate (for example, bedrock aquifer ground-water results cannot be interpreted according to the sampling area schema). Nonetheless, the data for all medium/source/location combinations (which are presented in Volume III), follow the organizational convention described.

The analytical results from QA/QC sites (that is, sites at which duplicate and triplicate samples were collected), where explicit identification of the site specific field sample was not stipulated, were subjected to random (equiprobable) selection prior to statistical analyses of the data. These same data were also used for the production of certain graphical summaries of the data that are presented in later sections of this Volume. As a result of this action, significant conceptual difficulties were avoided in dealing with the multiple sets of analytical results from QA/QC sites; namely, problems that are associated with the alternative procedure of attempting to represent the site by computing mean concentrations whenever below detection (B) or trace



```
                              * * R A W   D A T A   L I S T I N G * *
            THIS REPORT IS BASED ON VALIDATED DATA ENTERED INTO THE SYSTEM THROUGH 06/17/81     01   003

                                          *****************
                                          *** SITE DATA ***
                                          *****************

SAMPLING AREA 01 STATION 003                                          COORDS 400410 E 1122490 N MAP OVERL

                                         ******************
                                         *** SAMPLE DATA ***
                                         ******************

SAMPLE-ID A10212  MEDIUM AIR   SOURCE PFOAM  SAMPLE DATE 09/08/80  START TIME 0853  CONTRACTOR  GEOME
LOC L1  PUMP 4784        START/END/AVG FLOW 1239.90/1297.30/1268.60  END TIME 2053  DUR 0720 VOL   913.39

                                      *** ANALYSIS RESULTS ***

     METHOD  ECGCF     SPECIFIC METHOD             ANALYSIS LAB  SWRI     QUAN SIZE     0.0 N/A
   COMPOUND                           CAS    PC  CONCENTRATION        REPORTED CONC         COMMENT
 POLYURETHANE PLUGS  BELOW DETECTION LIMIT

                                         ******************
                                         *** SAMPLE DATA ***
                                         ******************

SAMPLE-ID A10429  MEDIUM AIR   SOURCE PFOAM  SAMPLE DATE 09/16/80  START TIME 0843  CONTRACTOR  GEOME
LOC L1  PUMP 4784        START/END/AVG FLOW 1205.00/1347.00/1276.00  END TIME 2043  DUR 0720 VOL   918.72

                                      *** ANALYSIS RESULTS ***

     METHOD  ECGCF     SPECIFIC METHOD             ANALYSIS LAB  GSLA     QUAN SIZE     0.0 N/A
   COMPOUND                           CAS    PC  CONCENTRATION        REPORTED CONC         COMMENT
 POLYURETHANE PLUGS  BELOW DETECTION LIMIT

                                         ******************
                                         *** SAMPLE DATA ***
                                         ******************

SAMPLE-ID A10616  MEDIUM AIR   SOURCE PFOAM  SAMPLE DATE 09/21/80  START TIME 0831  CONTRACTOR  GEOME
LOC L1  PUMP 5940        START/END/AVG FLOW 1272.40/1267.00/1269.70  END TIME 2031  DUR 0720 VOL   914.18

                                      *** ANALYSIS RESULTS ***

     METHOD  ECGCF     SPECIFIC METHOD             ANALYSIS LAB  GSLA     QUAN SIZE     0.0 N/A
   COMPOUND                           CAS    PC  CONCENTRATION        REPORTED CONC         COMMENT
 POLYURETHANE PLUGS  BELOW DETECTION LIMIT

                                         ******************
                                         *** SAMPLE DATA ***
                                         ******************

SAMPLE-ID A10298  MEDIUM AIR   SOURCE TENAX  SAMPLE DATE 09/08/80  START TIME 0853  CONTRACTOR  GEOME
LOC L1  PUMP 10616       START/END/AVG FLOW   28.21/  30.69/  29.45  END TIME 2053  DUR 0720 VOL    21.20

                                      *** ANALYSIS RESULTS ***

     METHOD  GCMST     SPECIFIC METHOD             ANALYSIS LAB  BCL      QUAN SIZE     0.0 N/A
   COMPOUND                           CAS    PC  CONCENTRATION        REPORTED CONC         COMMENT
BENZENE                            71-43-2 T01          3.679 UG/M3         78.000 NG/SM EXTRAPOLATED
O-DICHLOROBENZENE                  95-50-1 T07         49.009 UG/M3       1039.000 NG/SM EXTRAPOLATED
1,1,2,2-TETRACHLOROETHYLENE       127-18-4 T09          5.188 UG/M3        110.000 NG/SM EXTRAPOLATED
TOLUENE                           108-88-3 T10         41.745 UG/M3        885.000 NG/SM EXTRAPOLATED
DICHLOROMETHANE                    75- 9-2 T23   QUALITATIVE
PHENOL                            108-95-2 T24   QUALITATIVE
O-XYLENE                           95-47-6 T25   QUALITATIVE
M-XYLENE                          108-38-3 T26   QUALITATIVE
P-XYLENE                          106-42-3 T27   QUALITATIVE

                                         ******************
                                         *** SAMPLE DATA ***
                                         ******************

SAMPLE-ID A10485  MEDIUM AIR   SOURCE TENAX  SAMPLE DATE 09/16/80  START TIME 0844  CONTRACTOR  GEOME
LOC L1  PUMP 10616       START/END/AVG FLOW   30.60/  30.40/  30.50  END TIME 2044  DUR 0720 VOL    21.96

                                      *** ANALYSIS RESULTS ***

     METHOD  GCMST     SPECIFIC METHOD             ANALYSIS LAB  PEDC     QUAN SIZE     0.0 N/A
   COMPOUND                           CAS    PC  CONCENTRATION        REPORTED CONC         COMMENT
```

Figure 7. Sample Page of the Data Listing Presented in Volume II.

(T) values were obtained. However, the procedure followed requires that care must be exercised when attempting to compare Volume II results with Volume III summary tables.

The only statistical tests performed on the Love Canal monitoring data involved substance-by-substance comparisons between Declaration Area, Canal Area, and Control Area aggregations of the data. Differences in the extent of environmental contamination in areas of interest were assessed statistically by a difference of percentages test, using Fisher's exact test to determine probability values. The extent of contamination in an area was defined as the percent of positive determinations (qualitative identifications) of the substance of interest at a trace or greater concentration level. Differences in the degree of environmental contamination in areas of interest were assessed statistically through the use of a difference in medians test, again using Fisher's exact test for the computation of probability values. Due to the large number of substances monitored, and the large number of substance-by-substance comparisons that can be made, statistical inference problems may occur. The reader is cautioned to realize that for a given level of significance α, a proportion of results approximately equal to α will, by chance, demonstrate statistical significance. Such outcomes, known as Type I errors (that is, rejecting the null hypothesis when it is true), must be considered when attempting to evaluate the statistical results presented in Volume III.

The statistical criteria established for assessing the extent and degree of environmental contamination in an area of interest were as follows. First, directional alternative hypotheses were postulated, incorporating the expectation of greater contamination in the Canal Area than in the Declaration Area, and greater contamination in the Declaration Area than in the Control Area (control sites are identified for selected medium/source/location combinations in Appendix B, Table B-1). And second, a level of significance of $\alpha = 0.10$ was selected (as compared to the more commonly employed levels of 0.05 or 0.01) for rejection of the null hypothesis of no difference in environmental contamination between the areas monitored. This level of significance was selected to obtain acceptably high power in the statistical test procedures employed, particularly when comparing the Declaration Area monitoring data to the Control Area monitoring data for certain medium/source/location combinations. As a result of these two actions, the probability of detecting statistical trends in the monitoring data that were suggestive of the migration of contaminants from Love Canal into the Declaration Area was increased considerably above the usual practice.

3.5 LIMITATIONS

As was mentioned in Section 1.1.6, the EPA Love Canal study was limited by both time and budgetary constraints. As a result, medium-specific sample designs and site-specific sampling frames were employed, and a large number of field samples were collected over a relatively short time interval. Obviously, therefore, the 1980 EPA Love Canal study represents but a finite characterization of environmental conditions in the Love Canal Declaration Area, and retrospective assessment of the extent and degree of contamination present in the Declaration Area (for example, air pollution levels) at some past date is uncertain, and has not been performed.

CHAPTER 4
RESULTS OF THE INVESTIGATIONS

The major results of the EPA Love Canal environmental monitoring program have been organized by environmental medium and are presented in subsequent subsections of this report. The organization of this section on results deliberately follows the same sequence of topics that was presented in Section 1.2 of the Overview. The intent here is to provide the reader with additional details on sampling, analytical, and interpretive aspects of the Love Canal monitoring program.

4.1 HYDROGEOLOGIC PROGRAM

The hydrogeological study conducted by EPA at Love Canal was multidimensional. Integral parts included defining the geology and occurrence of ground water within the study area, locating areas of ground-water contamination (both vertically and laterally), and determining the directions and rates of movement of contaminants through the subsurface soils and rock.

The first phase of the program involved the collection and analysis of existing geological and hydrological data in order to guide the project through subsequent stages. Included in this phase, and occurring concurrently, were geophysical investigations using the most advanced techniques in ground-penetrating radar and electromagnetic conductivity. These activities were designed to determine the occurrence of ground water in the study area, to help locate potential plumes of contamination moving from the former canal, and to provide a partial basis for selecting monitoring well site locations.

The second phase of the program involved a test drilling program that was initially designed to determine the number and depth of permeable water-bearing zones existing vertically in both the overburden and underlying bedrock, and to determine if ground water in the overburden and bedrock were connected or if separate aquifers existed. Data developed during the test drilling program served to guide the subsequent installation of monitoring wells. The 174 monitoring wells installed by EPA at Love

Canal were used for the purpose of obtaining samples of the subsurface materials at selected drilling sites, obtaining water-level data, determining aquifer flow characteristics, and collecting a large number of samples of ground water for chemical analysis. Stringent requirements were imposed on all aspects of well construction in order to avoid potential cross-contamination of water-bearing zones. Substances of interest that were routinely determined in ground-water samples are identified in Appendix A of this Volume.

The third phase of the hydrogeologic program was the development of a verified ground-water model for predicting the movement of contaminants in the ground water under varying conditions of recharge and discharge. An extensive report on the results of this effort, Final Report on Ground-Water Flow Modeling Study of the Love Canal, New York, is available from NTIS.

Figures 8 and 9 identify the locations of wells drilled in the general Love Canal area as part of the EPA hydrogeologic program. Figure 8 identifies the location of monitoring wells in the vicinity of Love Canal that were drilled into the overburden and used to monitor contamination in the shallow system; these wells were referred to as "A Wells." In Figure 9, the location of monitoring wells in the vicinity of Love Canal that were drilled into the underlying bedrock, and used for monitoring contamination in the bedrock aquifer, are indicated; these wells were referred to as "B Wells."

4.1.1 Geology of the Love Canal Area

In order to understand the potential for contamination migrating from the former canal, a thorough understanding of the geology, as well as the occurrence and movement of ground water, at the site was necessary. The information obtained from the geological portion of the program was used to optimize the placement of ground-water monitoring wells and was also used partially to guide the selection of soil sampling locations.

4.1.1.1 Geological Setting

During the Pleistocene epoch, western New York State experienced several periods of glaciation. As a result, the general Love Canal area exhibits features that are characteristic of glacial erosion and deposition. Bedrock in the vicinity of Love Canal consists of a unit known as Lockport Dolomite, a mineral deposit composed of calcium magnesium carbonate. Underlying the Lockport Dolomite is a relatively impermeable unit referred to as Rochester Shale. The Lockport Dolomite was encountered during well drilling activities at a depth of approximately 20 to 45 feet below the land surface, and ranged in thickness from approximately 160 to 180 feet. Generally, the Lockport Dolomite may be

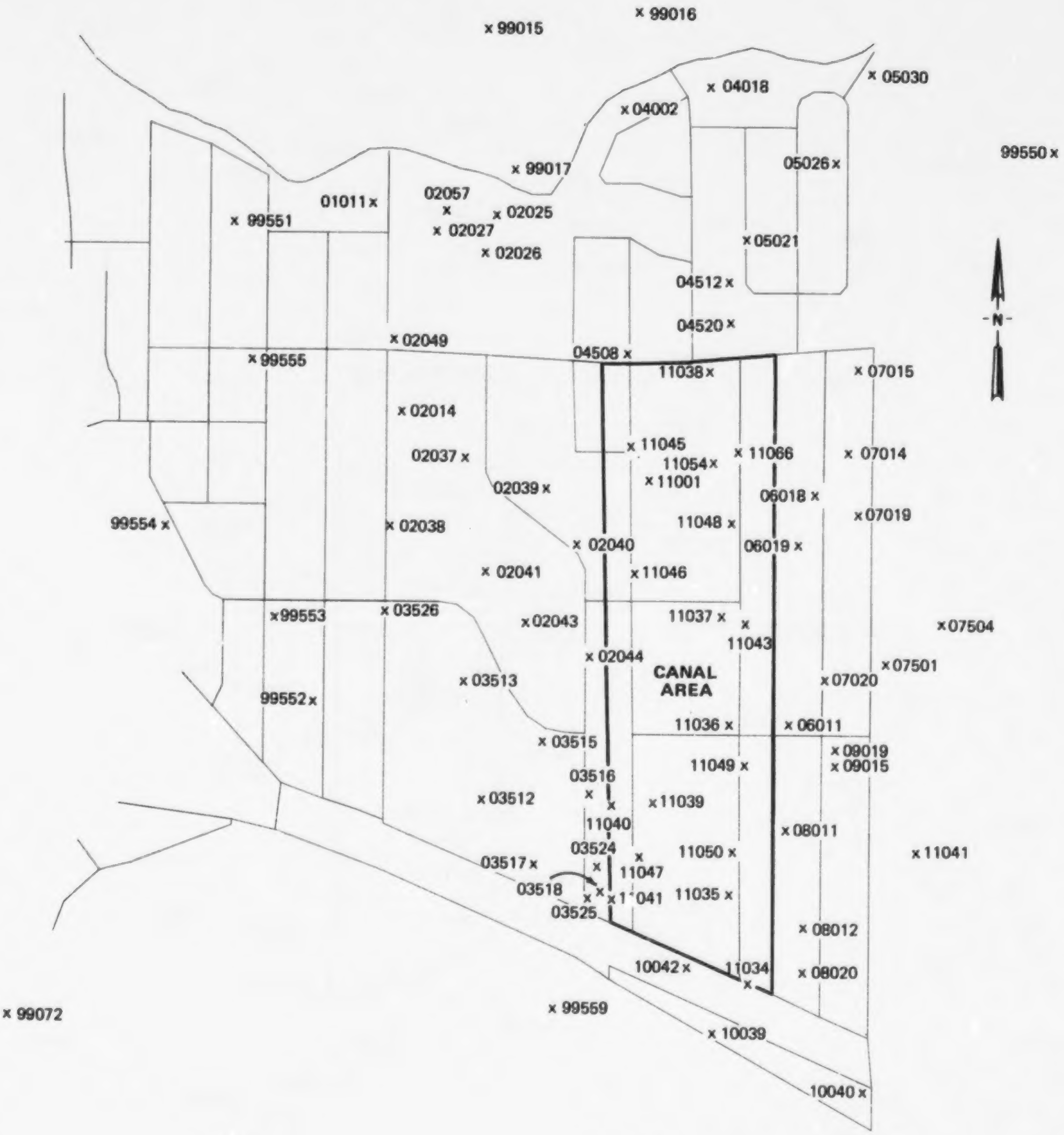

x 99015
x 99016
x 05030
x 04018
x 04002
99550 x
05026 x
x 99017
01011 x
02057
x
x 02025
x 99551
x 02027
x 05021
x 02026
04512 x
N
04520 x
x 02049
04508 x
x 99555
11038 x
x 07015
x 02014
x 11045
x 11066
x 07014
02037 x
11054 x
x 11001
02039 x
06018 x
x 07019
99554 x
x 02038
11048 x
x 02040
06019 x
x 02041
x 11046
x 99553
x 03526
11037 x
x
x 07504
x 02043
11043
x 02044
x 07501
CANAL
AREA
x 03513
x 07020
99552 x
11036 x
x 06011
x 03515
x 09019
x 09015
11049 x
03516
x
x 03512
x
x 11039
11040
x 08011
03524
x
11050 x
x 11041
03517 x
x
11047
03518
x
x
x 11041
11035 x
03525
x 08012
10042 x
11034
x
x 08020
x 99072
x 99559
x 10039
10040 x

Figure 8. Well A (Overburden) Installation Site Codes.

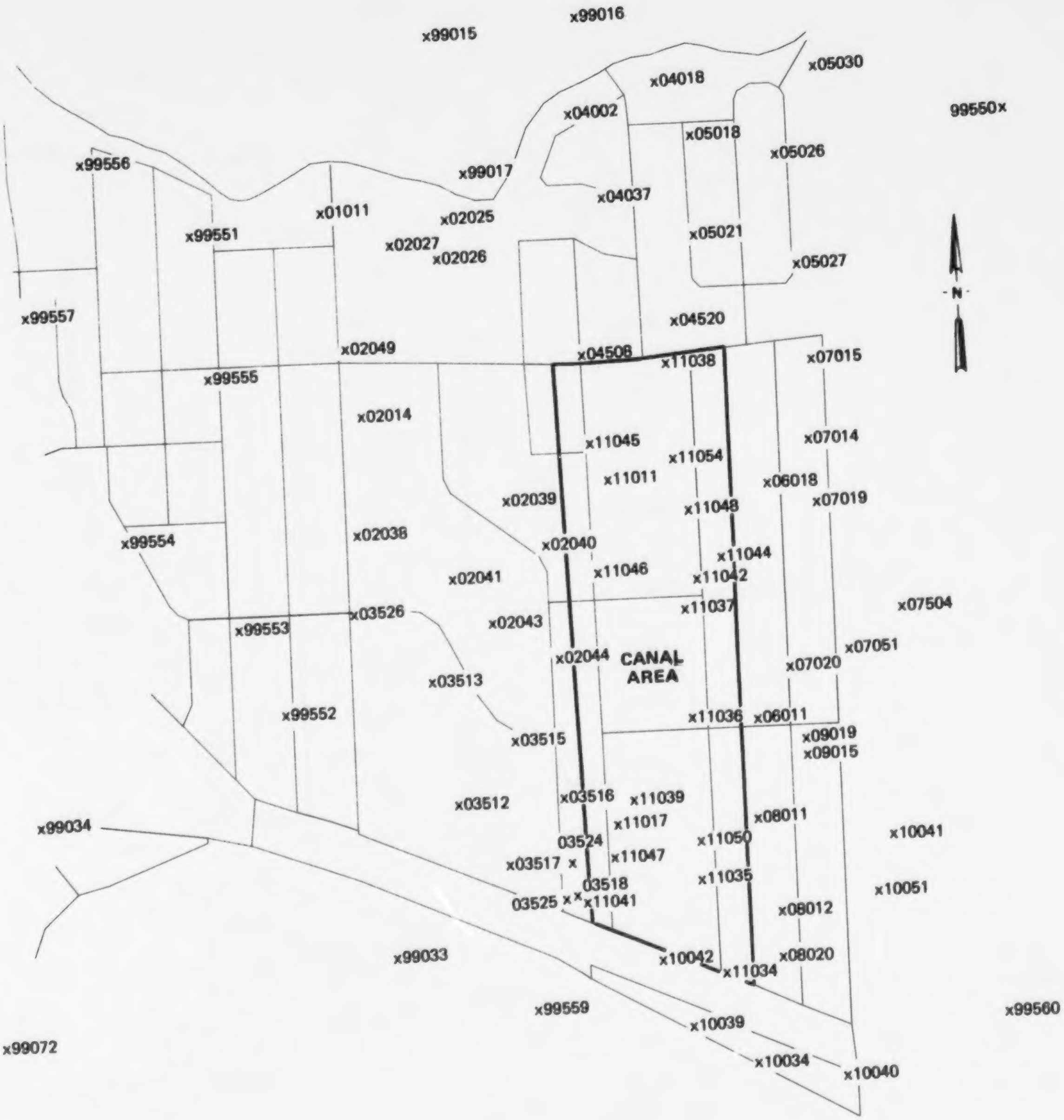

x99016
x99015
x05030
x04018
x04002
99550x
x05018
x05026
x99556
x99017
x04037
x01011
x02025
x99551
x05021
x02027
x02026
x05027
N
x99557
x04520
x02049
x04508
x11038
x07015
x99555
x02014
x11045
x07014
x11054
x11011
x06018
x02039
x07019
x11048
x99554
x02036
x02040
x11044
x11046
x11042
x02041
x07504
x11037
x03526
x02043
x99553
x07051
x02044
CANAL
AREA
x07020
x03513
x99552
x11036
x06011
x03515
x09019
x09015
x03516
x11039
x03512
x08011
x99034
x11017
03524
x10041
x11050
x03517 x
x11047
03518
x11035
x10051
03525 x x x11041
x08012
x99033
x10042
x11034
x08020
x99559
x99560
x10039
x99072
x10034
x10040

Figure 9. Well B (Bedrock) Installation Site Codes.

described as a dark gray to brown, massive to thin-bedded dolomite, locally containing small, irregularly shaped masses of gypsum and calcite. The Lockport Dolomite was found to dip towards the south at a rate of approximately 30 feet per mile.

In the general Love Canal area, the Lockport Dolomite is overlaid by a deposit of glacial till ranging in thickness from approximately 1 to 5 feet; in the Canal Area the till was found to vary from approximately 5 to 20 feet thick. The glacial till consists of an unsorted mixture of clay, sand, and rocks that was deposited on the Lockport Dolomite by the advance and retreat of glaciers. From field testing activities the glacial till was found to be relatively impermeable (K of approximately 10^{-7} cm/s).

Layers of clay, silt, and fine sand exist above the glacial till and were found to vary in thickness from approximately 6 to 29 feet. These materials were deposited in the area by lakes that were formed by the melting and retreat of glaciers during the late Quaternary period. Two glacial lakes were chiefly responsible for these deposits. The older glacial lake, Lake Dana, deposited reddish sediments, which had eroded from bedrock to the north, on top of the till. The lacustrine deposits attributable to Lake Dana were found to vary from approximately 2 to 20 feet thick, and were characterized as very moist to wet, very plastic, very sticky, silty-clay to clay. The permeability of these materials was found to be relatively low (K of approximately 10^{-8} cm/s).

Above the Lake Dana deposits were the deposits of Lake Tonawanda, which ranged in thickness from approximately 3 to 8 feet. The materials deposited by Lake Tonawanda tended to be coarser, reddish brown to gray sediments that were characterized as somewhat moist, firm, varved, silty-clay to clay. At a depth of approximately 5 to 8 feet below surface levels the lacustrine deposits were found to be extremely firm to very firm silty-clay, and vertical dessication cracks have sometimes been noted as present (according to reports prepared by other investigators). The permeability of the Lake Tonawanda deposits was found to be generally low (K of approximately 10^{-7} cm/s).

Above the Lake Tonawanda deposits were layers of silty sand, clayey silt, and other fill materials varying in thickness from but a few inches to approximately 3 feet in the general Love Canal area. The permeability of these materials was found to be greater than the underlying clays (K greater than or equal to approximately 10^{-5} cm/s). Also present in the lacustrine sediments were random deposits of more sandy materials occurring in the form of sand lenses. These more permeable sandy zones were found to occur neither in considerable thickness nor to extend over large areas. Rather, these features were found to occur as typically small, generally disconnected deposits as is characteristic of heterogeneous lacustrine material. Figure 10 summarizes in general terms the geologic units found in the Love Canal area.

4.1.1.2 Topography and Drainage

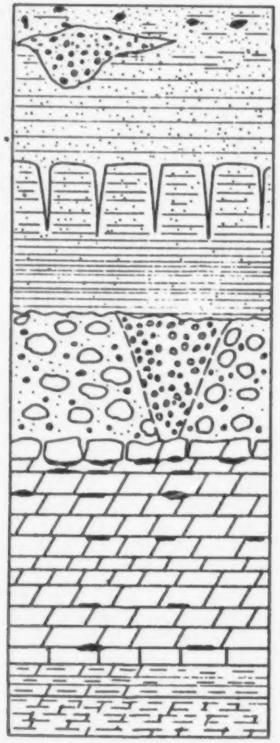
The Love Canal site is located on the flood plain of the Niagara River within the eastern limit of the City of Niagara Falls, New York. The eastern border of the Declaration Area adjoins, and is partially located in, the Town of Wheatfield, New York. The general area (Figure 11) is relatively flat and is dominated by three major features: the United States and Canadian Falls; the Niagara gorge; and the Niagara Escarpment.

The Niagara Escarpment, a steep cliff marking the end of high land, extends in an easterly direction from the Niagara River immediately south of Lewiston, New York to well beyond the general Love Canal area. At the Niagara River, the escarpment is approximately 200 feet high, and gradually diminishes toward the east into a broad, gently-sloping incline. North of the escarpment the land slopes gently towards Lake Ontario. South of the escarpment the land slopes gently toward the upper Niagara River.

Streams in the general Love Canal area eventually flow into the Niagara River. On the north, Bergholtz Creek and Black Creek (which joins Bergholtz Creek near 96th Street) flow in an east-to-west direction. Bergholtz Creek joins Cayuga Creek at a point northwest of the former canal near the intersection of Cayuga Drive and 88th Street. Cayuga Creek flows in a generally north to south direction and empties into the Little Niagara River near South 87th Street. The Little Niagara River joins the Niagara River on the west side of Cayuga Island. Given the existence of certain climate- and weather-related conditions and the gentle slopes of the three creekbeds, local and temporary reversals of water flow direction are known to occur in Cayuga, Bergholtz, and Black Creeks.

Prior to the early 1970's, a number of surface soil features, sometimes referred to as swales, existed in the general Love Canal area. Swales were generally shallow depressions (less than 10 feet deep) that presumably served to preferentially drain the area of surface water run-off. The location of known former swales in the general Love Canal area are depicted in Figure 2 by superimposed wavy lines. The identification of former swales throughout the area was performed by the Remote Sensing Program, School of Civil and Environmental Engineering, Cornell University, from the inspection of historical aerial photographs of the site taken between 1938 and 1966.

A variety of arguments have been offered concerning the potential importance of swales in contributing to the migration of contaminants from Love Canal to the adjacent residential areas.



System		Formation Unit	Thickness (Feet)	General Geologic and Hydrologic Characteristics
Quaternary	Late	Fill	0.1-3	- Covers nearly entire study area - Varies from local soil material to construction rubble and industrial wastes
		Lacustrine Deposits	6-29	- Sand lenses randomly occur as elongated lacustrine deposits throughout region and consist of loamy to sandy clay; sometimes exposed at surface in undisturbed areas - Total thickness of former glacial lake deposits increases from north to south in vicinity of canal - Upper sequence deposited in former Lake Tonawanda (3-8 feet thick) is reddish brown to gray, moist, firm to very firm, varved, silty-clay to clay; dessication cracks reported in selective areas within sequence - Lower sequence (2-20 feet thick) attributable to former Lake Dana is reddish brown, very moist to wet, very plastic, very sticky, silty-clay to clay - Permeability of lacustrine deposits is generally low
		Glacial Till	1-25	- Reddish brown, moist, firm, silty to sandy clay with gravel and cobbles; sandy zones, well-sorted gravel - Two or three ridges of till oriented NE-SW are in Canal Area - Generally low permeability - Approximately 5-20 feet thick in Canal Area
Silurian	Middle	Lockport Dolomite	160-180	- Dark gray to brown, massive to thin bedded dolomite dipping at low angle to south; secondary deposits of sulfides, sulfates, and carbonates occur throughout the formation - Principal aquifer in Niagara Falls area; major producing zones in upper part of formation - Artesian and unconfined water table conditions exist associated with vertical fracture zones, cavities formed by solution of minerals and between bedding planes - Vertical joint system hydraulically connected to Niagara River
	Lower	Rochester Shale	60	- Dark-gray calcareous shale; relatively impermeable

Figure 10. Generalized Columnar Section of Geologic Units in Love Canal Area.

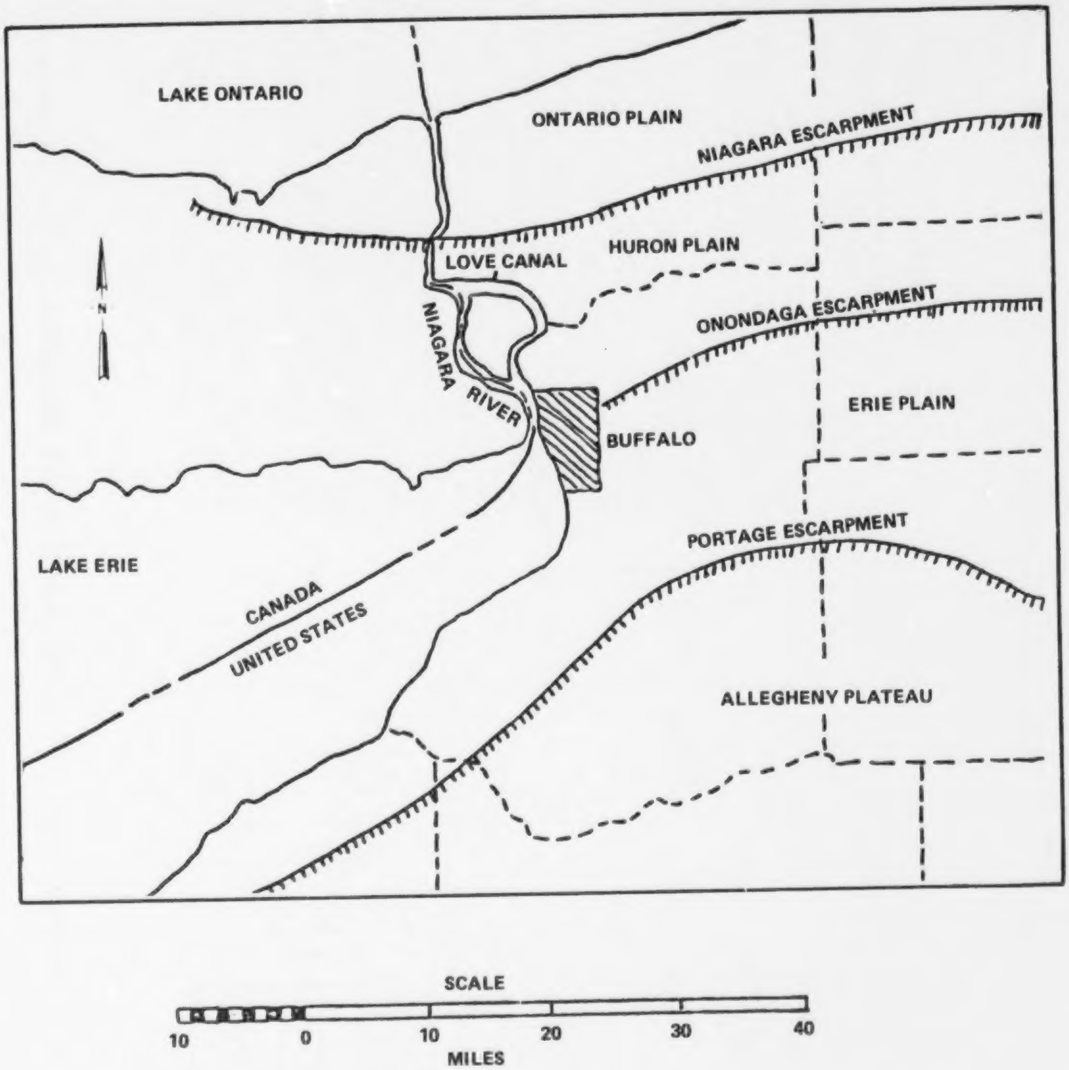

LAKE ONTARIO
ONTARIO PLAIN
NIAGARA ESCARPMENT
HURON PLAIN
LOVE CANAL
N
NIAGARA RIVER
ONONDAGA ESCARPMENT
ERIE PLAIN
BUFFALO
LAKE ERIE
CANADA
UNITED STATES
PORTAGE ESCARPMENT
ALLEGHENY PLATEAU
SCALE
10
0
10
20
30
40
MILES

Figure 11. Index Map Showing Location of Project Area and Physiographic Provinces.

For example, it has been argued by some that if the former swales were filled with rubble and more permeable soils during periods of residential construction activity near Love Canal, then they may have preferentially allowed chemicals to migrate some distance from the dump site into the surrounding neighborhood, particularly in response to certain climate influenced ground-water conditions (the so-called "overflowing bathtub" analogy frequently used to describe unusually high ground-water conditions at the site during the period 1976 to 1978). Alternatively, it has been offered that when the landfill was open, water impounded in the canal was contaminated by dumping activities and displaced from the canal into the still open intersecting swales, and subsequently into the surrounding neighborhood. Finally, it has been argued that if the swales had been filled with already contaminated soils that were removed from the Love Canal site after dumping activities were concluded in 1953 (the so-called "transport by dump truck" conjecture), then the surrounding neighborhood would exhibit isolated areas of relatively low-level contamination in some of the former swales and other low-lying areas.

As a result of the generally level topography of the site, surface water run-off was historically poor. During rainy periods, areas of ponded water and marshy ground formed, typically to the southwest and southeast of the canal. Houses that were later built in areas where water problems historically occurred have been referred to by other investigators as "wet" houses; for example, a wet/dry dichotomy of Love Canal houses was developed and used for classification purposes by NYS DOH in their epidemiological investigations at Love Canal. The NYS DOH wet/dry classification scheme was also used by EPA for the selection of a number of sampling sites.

At the present time, surface-water drainage principally occurs in the general Love Canal area through a system of storm sewers installed by the City of Niagara Falls. Typically, storm sewers in the Love Canal Declaration Area were found to be approximately 10 feet deep.

Of particular interest to this investigation were the storm sewer lines that virtually surround the Canal Area. On 97th Street a storm sewer line starts at approximately Read Avenue, heads northward, and eventually discharges into Black Creek near 96th Street. A storm sewer lateral on Read Avenue, terminating in a catch basin located approximately midpoint between 97th and 99th Streets, was built by the city in 1960. Prior to remedial construction, the lateral on Read Avenue was connected to the 97th Street northward flow storm sewer line. On Colvin Boulevard a storm sewer line originating near 98th Street heads westward and joins the 97th Street storm sewer. In addition, prior to remedial construction a catch basin installed for drainage purposes by the City of Niagara Falls near the former canal boundary, along the property line at 949-953 97th Street, was connected to the 97th Street northward flowing storm sewer line. Figure 12 shows the approximate location of the features just mentioned and other relevant Canal Area storm sewers.

The southward flowing storm sewer line on 97th Street originates near Read Avenue and connects to a storm sewer line on Frontier Avenue that flows eastward, and eventually discharges into the Niagara River at the so-called 102nd Street outfall. Prior to remedial construction, a storm sewer lateral on Wheatfield Avenue, terminating in a catch basin located approximately 170 feet east of 97th Street, was connected to the 97th Street southward flowing storm sewer line.

On 99th Street the northward flowing storm sewer line originates near Read Avenue and eventually discharges into Black Creek (which is located in a below-grade culvert from 98th Street to approximately the imaginary northward extension of 102nd Street), between 101st and 102nd Streets. The southward-flow 99th Street storm sewer consists of a portion between Read and Wheatfield Avenues, and another portion originating near Wheatfield Avenue. The portion of the 99th Street storm sewer line between Read and Wheatfield Avenues flows south and turns eastward on Wheatfield Avenue, turns south again on 101st Street, and eventually discharges into the Niagara River at the 102nd Street outfall. Prior to remedial construction, the French drain built around the 99th Street Elementary School was connected to the 99th Street storm sewer line just north of Wheatfield Avenue. (See Figure 12). In addition, prior to remedial construction, a storm sewer lateral on Wheatfield Avenue, terminating in a catch basin located approximately 170 feet west of 99th Street, was connected to the 99th Street storm sewer line at Wheatfield Avenue. The portion of the 99th Street storm sewer line originating south of Wheatfield Avenue is connected to the Frontier Avenue storm sewer line and eventually discharges into the Niagara River at the 102nd Street outfall.

According to NYS DEC field inspection notes and NYS DOH reports, the storm sewer lines installed by the City of Niagara Falls around Love Canal were built without granular bedding and the trenches were backfilled with the excavated natural soils. As a result of this construction practice, a "curtain of clay" around the site, likely severing all naturally occurring more permeable soil pathways leading from the former canal (including filled former swales), may have been built inadvertently by the city. The storm sewer line currently under Frontier Avenue, which was relocated by NYS DOT in 1968, does have a granular bedding, but it was encompassed by the barrier drain system constructed by NYS DEC. The storm sewer leads and catch basins on Read and Wheatfield Avenues were all removed during remedial construction, as was the catch basin and pipe located near the former canal on 97th Street, and the entire French drain system

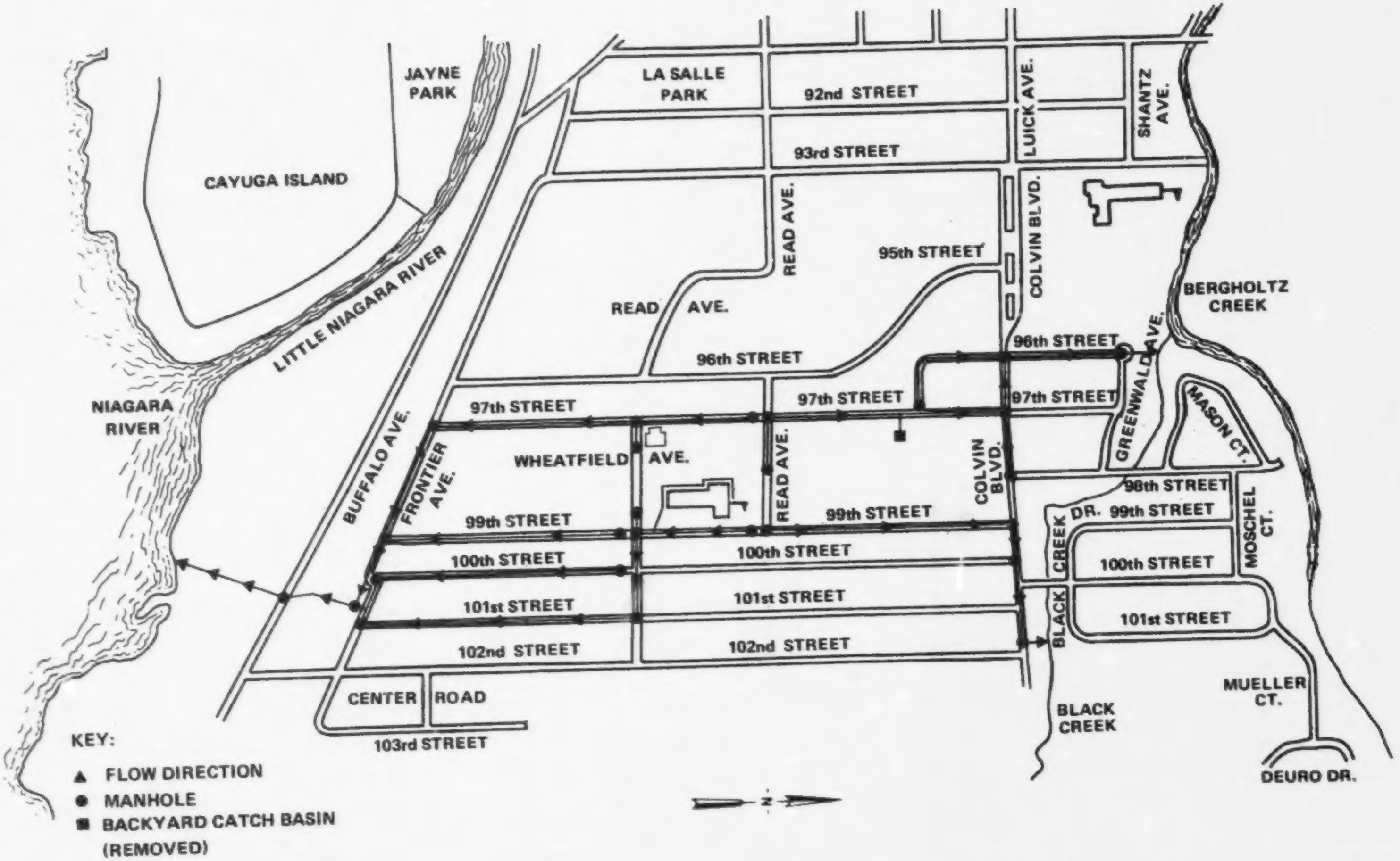

JAYNE PARK
LA SALLE PARK
92nd STREET
93rd STREET
LUICK AVE.
SHANTZ AVE.
CAYUGA ISLAND
LITTLE NIAGARA RIVER
READ AVE.
95th STREET
COLVIN BLVD.
BERGHOLTZ CREEK
96th STREET
GREENWALD AVE.
97th STREET
MASON CT.
NIAGARA RIVER
BUFFALO AVE.
FRONTIER AVE.
WHEATFIELD AVE.
98th STREET
99th STREET
CREEK DR.
MOSCHEL CT.
100th STREET
101st STREET
102nd STREET
BLACK CREEK
CENTER ROAD
103rd STREET
MUELLER CT.
DEURO DR.
N
KEY:
▲ FLOW DIRECTION
● MANHOLE
■ BACKYARD CATCH BASIN (REMOVED)

Figure 12. Location of Storm Sewers Near Love Canal.

around the 99th Street Elementary School. Across Wheatfield Avenue, a natural gas main, as well as a sanitary sewer line installed by the City of Niagara Falls in 1957, still remain. According to NYS DEC field inspection notes, neither line was constructed with a granular bedding and both were intercepted by the barrier drain system installed by NYS DEC. In 1980 the City of Niagara Falls plugged the Wheatfield Avenue sanitary sewer line near the intersection of Wheatfield Avenue and 99th Street.

As a result of the relatively close proximity of storm sewer lines to Love Canal, interest was focused on characterizing their current transport of contaminants to area creeks and rivers. It was recognized that prior to remedial construction, a number of sources may have contributed to storm sewer contamination including: (1) overland flow of contaminants that were likely captured by curb drains near ring 1 houses; (2) subsurface migration and infiltration of contaminants into the storm sewers, particularly through the storm sewer laterals on Read and Wheatfield Avenues, the catch basin and pipe located near the former canal at 949-953 97th Street and connected to the 97th Street northward-flow storm sewer line, and the French drain built around the 99th Street Elementary School; and (3) the discharge of potentially contaminated water and sediment taken-up by basement sump pumps in ring 1 and ring 2 houses and discharged into Canal Area storm sewers. As a result of remedial construction activities and the evacuation of ring 1 and ring 2 families by 1979, the only potentially remaining source of continuing storm sewer contamination was through the residual subsurface migration and infiltration of contaminants into storm sewer lines on 97th and 99th Streets, Colvin Boulevard, and Frontier Avenue.

4.1.1.3 Occurrence of Ground Water

Ground water was found to occur in the Lockport Dolomite in three types of openings: (1) bedding planes--horizontal planes that separate individual layers of the rock; (2) vertical joints--fractures that interrupt the horizontal continuity of the rock unit; and (3) solution cavities--cavities in the rock from which gypsum and calcite have been dissolved. Most of the water moving through the upper portion of the Lockport Dolomite was found to move through the horizontal bedding planes contained in the top 10 to 16 feet of the unit. Ground-water flow in the upper portion of the Lockport (the top 20 feet of the unit), was found to be affected by the major trends of vertical fractures connecting the bedding planes. The lower portion of the Lockport (145 to 170 feet thick) was characterized by seven distinct water-bearing zones having well-developed bedding plane separations. Flow in the lower portion of the Lockport Dolomite was found to generally follow the inclination of the formation.

Field tests conducted on the bedrock aquifer yielded the following results: (1) the Lockport Dolomite is not a homogeneous aquifer, but contains distinct water-bearing zones; (2) the upper portion of the rock has significant vertical permeability; (3)

the primary water-bearing zones are in the upper part of the aquifer; (4) fractures have a substantial effect on the rate and direction of ground-water movement in the upper portion of the bedrock; (5) the upper portion of the bedrock aquifer is hydraulically connected to the Niagara River; and (6) the bedrock aquifer in the vicinity of Love Canal is confined below by the Rochester Shale and above by the glacial till, and is artesian.

The deposits above the Lockport Dolomite (the overburden material) were found not to be significant sources of water for the area. The unconfined water-table aquifer existing in the overburden material was found to be bounded by Bergholtz and Black Creeks on the north, Cayuga Creek on the west, and the Little Niagara and Niagara Rivers on the south. In general, the glacial till and the two silty-clay units were found to be of low permeability with small areas of sandy layers occurring within where ground water could move more readily.

4.1.2 Geophysical Investigations

The geophysical investigations conducted at Love Canal were performed using an integrated approach employing multiple surface remote-sensing techniques. This approach was adopted in order to permit the correlation of data records obtained from two or more remote sensing techniques employed at a particular location. Due to technical (that is, instrument) requirements, geophysical measurements were conducted only in those areas around Love Canal that were relatively free from residential interferences. The techniques listed in Table 5 summarize the geophysical methods employed at Love Canal, their mode of measurement, and the type of information each technique provided.

4.1.2.1 Objectives of the Geophysical Investigations

The overall goal of the geophysical investigations performed at Love Canal was to provide basic information concerning the hydrogeologic characteristics of the site. Specific objectives were:

1. To furnish information concerning the natural hydrogeologic variation of the site that could aid in understanding the ground-water transport of contaminants from the former canal.

2. To investigate the former canal and Canal Area using geophysical methods in order to tentatively identify and assess the potential for migration of contaminants from the site.

3. To provide data that would aid in the placement of some monitoring wells used to obtain information on ground-water contamination.

TABLE 5. GEOPHYSICAL METHODS AND APPLICATIONS

Method	Responds to Changes in:	Mode of Measurement	Application to Love Canal Setting
Ground Penetrating Radar	Complex dielectric constant	Continuous	--Provides continuous soil profiles to 3-6 feet --Reveals changes in soil stratigraphy and drainage patterns, and discerns areas of fill
Electromagnetics			
• Shallow EM	Bulk electrical conductivity	Continuous and station measurements	--Provides continuous spatial or station measurements of bulk conductivity to depths of approximately 18 feet --Reveals spatial changes in geo/hydrologic conditions and areas of conductive contamination
• Deep EM	Bulk electrical conductivity	Continuous and station measurements	--Provides continuous spatial or station measurements of bulk conductivity to depths of 45-50 feet --Shows spatial changes in geo/hydrologic conditions and discriminates areas of conductive contamination
Resistivity Sounding	Bulk electrical resistivity	Station measurements	--Provides data on changes in resistivity with depth --Enables detailed assessment of selected anomalies delineated in EM data
Seismic			
• Reflection	Soil or rock "velocity" contrasts	Station measurements	--Provides data on subsurface stratification
• Refraction	Soil or rock "velocity" contrasts	Station measurements	--Provides data on subsurface stratification, thickness, and depth of layers --Provides a measurement of the "velocity" or density of the soil or lithified components
Metal Detector	Electrical conductivity	Continuous	--Provides a means of mapping location and estimating quantity of buried metals (e.g., barrels) to a maximum depth of 5-10 feet for single targets
Magnetometer	Magnetic	Continuous	--Provides a means of mapping locations and estimating quantity of buried ferrous metals at depths up to 10-18 feet for single targets

4. To identify subsurface anomalies (which may include such features as swales and sand lenses) that may serve as preferential transport pathways for the migration of contaminants.

4.1.2.2 Major Results of the Geophysical Investigations

The multiple remote sensing geophysical methods used at Love Canal provided information on the geological variability of the general Love Canal area, and yielded suggestive information concerning the detection and delineation of potential migration pathways from the former canal. Figure 13 illustrates the type of information obtained from one of the remote sensing (shallow electromagnetic) geophysical methods used; the figure depicts the likely presence of contaminants located directly in and immediately adjacent to the landfill. A graphical summary of the inferred findings from the geophysical investigations conducted at Love Canal is presented in Figure 14. More detailed information on the results of the geophysical investigations conducted at Love Canal can be found in Geophysical Investigation Results, Love Canal, New York, available from NTIS.

4.1.3 Hydrology of the Love Canal Area

The hydrology of the general Love Canal area was determined from a combination of activities that incorporated: (1) reviewing the results of studies previously conducted in the region; (2) the results obtained from EPA geophysical surveys of the general Love Canal area; (3) the results obtained from EPA geological surveys of the area conducted during the construction of ground-water monitoring wells; and (4) the development and verification of a ground-water movement model of the area.

As part of the hydrogeologic program, a total of 174 ground-water monitoring wells (A and B Wells) were installed throughout the general area. During the investigation, five different types of wells were constructed. Monitoring wells installed in the overburden and screened in the silty clays above the glacial till were referred to as A Wells. Shallow bedrock monitoring wells were drilled 5 feet into the Lockport Dolomite and were referred to as B Wells. C Wells were monitoring wells drilled through the dolomite and into the underlying Rochester Shale. D Wells were originally B Wells that were extended to greater depths in the dolomite for hydrogeologic testing purposes. And T Wells were wells that were screened at various levels in the overburden for hydrogeologic testing purposes. The distribution of well types constructed during the program was: 89 A Wells; 85 B Wells; 4 C Wells; 3 B Wells were modified to D Wells; and 4 T Wells. A complete description of the hydrogeologic program, including well logs and as-built diagrams for all wells, can be found in the report The Ground-Water Monitoring Program at Love Canal, available from NTIS. Figures 15 and 16 illustrate the typical installation of shallow overburden and bedrock wells at Love Canal.

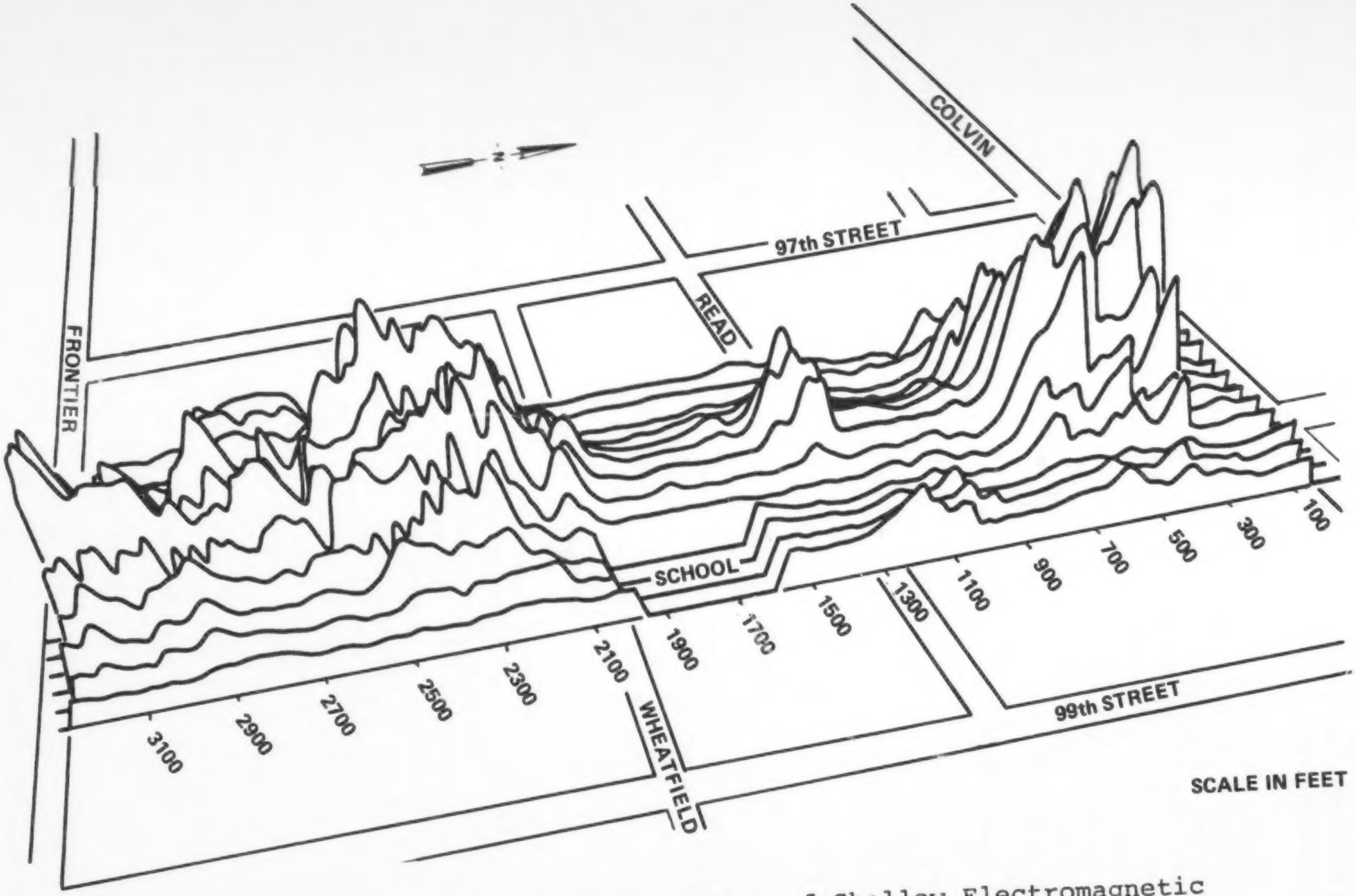


Figure 13. Three Dimensional Plot of Shallow Electromagnetic Conductivity Data from Canal Area (WNW View).

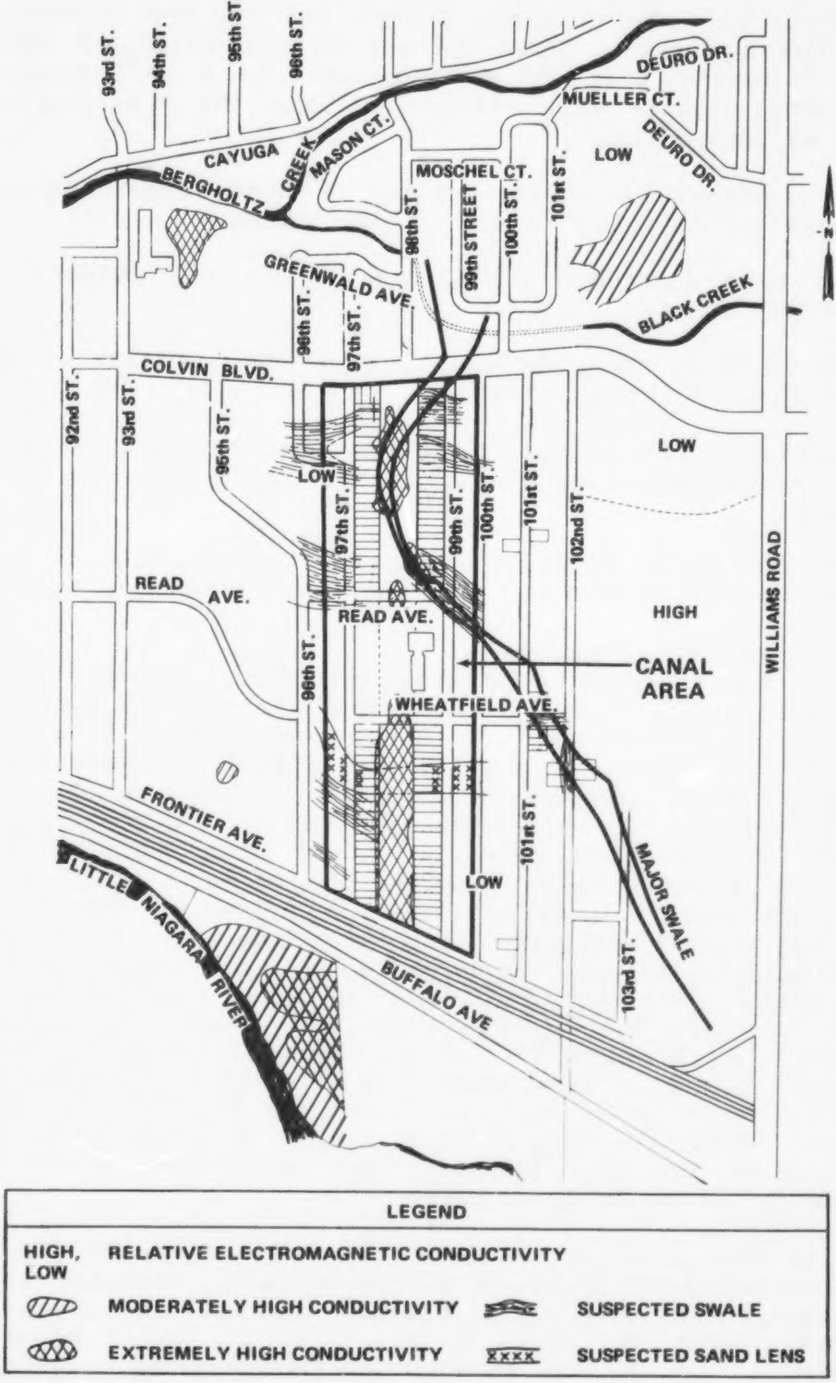

93rd ST.
94th ST.
95th ST.
96th ST.
DEURO DR.
MUELLER CT.
DEURO DR.
CAYUGA
CREEK
MASON CT.
BERGHOLTZ
MOSCHEL CT.
98th ST.
99th STREET
100th ST.
101st ST.
LOW
N
GREENWALD AVE.
BLACK CREEK
96th ST.
97th ST.
COLVIN BLVD.
92nd ST.
93rd ST.
95th ST.
LOW
LOW
97th ST.
99th ST.
100th ST.
101st ST.
102nd ST.
READ
AVE.
READ AVE.
HIGH
WILLIAMS ROAD
CANAL
AREA
96th ST.
WHEATFIELD AVE.
FRONTIER AVE.
101st ST.
LOW
MAJOR SWALE
103rd ST.
LITTLE NIAGARA RIVER
BUFFALO AVE
LEGEND
HIGH, LOW
RELATIVE ELECTROMAGNETIC CONDUCTIVITY
MODERATELY HIGH CONDUCTIVITY
SUSPECTED SWALE
EXTREMELY HIGH CONDUCTIVITY
SUSPECTED SAND LENS

Figure 14. Site Map Showing Major Results of Geophysical Survey.

Hydrologic testing of the bedrock aquifer was conducted using pumping tests to determine the transmissivity and storage coefficient of the aquifer. These values were determined empirically to be 0.015 square feet per second and 1.49×10^{-4} respectively. The following results were determined from the hydrologic testing conducted at Love Canal.

1. The Lockport Dolomite is not a homogeneous aquifer, but contains distinct water-bearing zones.
2. The upper portion of the unit has significant vertical permeability.
3. The primary water-bearing zones are located in the upper portion of the dolomite.
4. Fractures substantially affect both the rate and direction of ground-water movement in the upper portion of the bedrock.
5. In the well locations tested, no hydraulic connection apparently exists between the overburden and the bedrock.

4.1.3.1 Ground-Water Movement

The Lockport Dolomite aquifer maintains steady-state flow on a regional basis by recharge from the topographic high occurring near the Niagara Escarpment. Discharge generally occurs along the Niagara Escarpment, along the gorge wall of the lower Niagara River, towards the covered conduits of the Niagara Power Project, and along parts of the upper Niagara River. In the general Love Canal area, the gradient of ground-water movement in the dolomite is south and southwesterly towards the upper Niagara River. On the basis of bedrock aquifer tests conducted by EPA at Love Canal, it was estimated that if contaminants were to enter the Lockport Dolomite at the southern end of Love Canal, and assuming no attenuation, the average length of time required for the contaminants to reach the upper Niagara River would be approximately 1,000 days. In Figures 17 and 18 the potentiometric surface of the Lockport Dolomite is presented from both a regional and local perspective. The data used to construct Figure 17 were derived from R. H. Johnston, Ground Water in the Niagara Falls Area, New York, State of New York Conservation Department Water Resources Commission Bulletin GW-53 (1964).

As was mentioned previously, the shallow ground-water system in the general Love Canal area is probably bounded toward the north by Bergholtz and Black Creeks, toward the west by Cayuga Creek, and toward the south by the Little Niagara River and the Niagara River. In Figure 19 the static water table of the overburden aquifer is presented. The elevations shown in Figure 19 indicate that during the study period, discontinuities likely

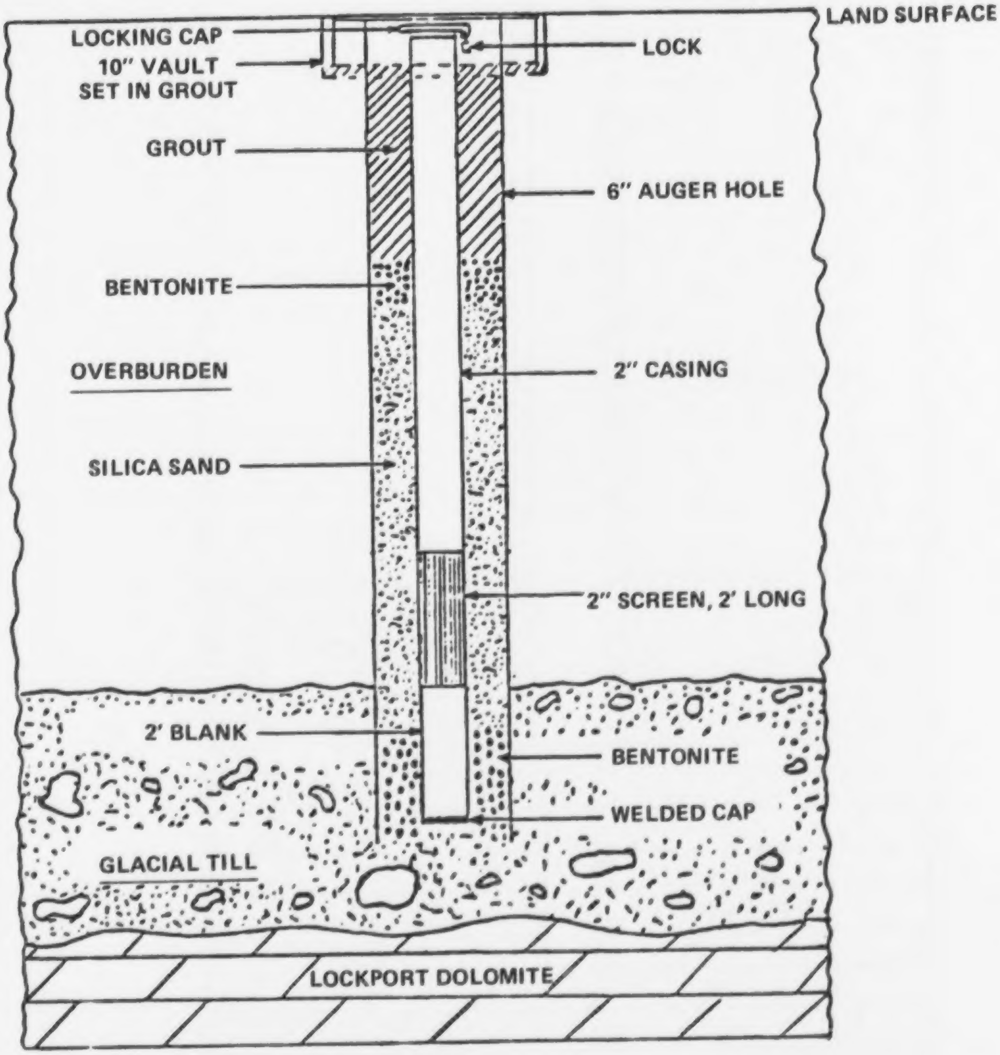

LAND SURFACE
LOCKING CAP
LOCK
10" VAULT SET IN GROUT
GROUT
6" AUGER HOLE
BENTONITE
OVERBURDEN
2" CASING
SILICA SAND
2" SCREEN, 2' LONG
2' BLANK
BENTONITE
WELDED CAP
GLACIAL TILL
LOCKPORT DOLOMITE

Figure 15. Completed Shallow (Overburden) Well.

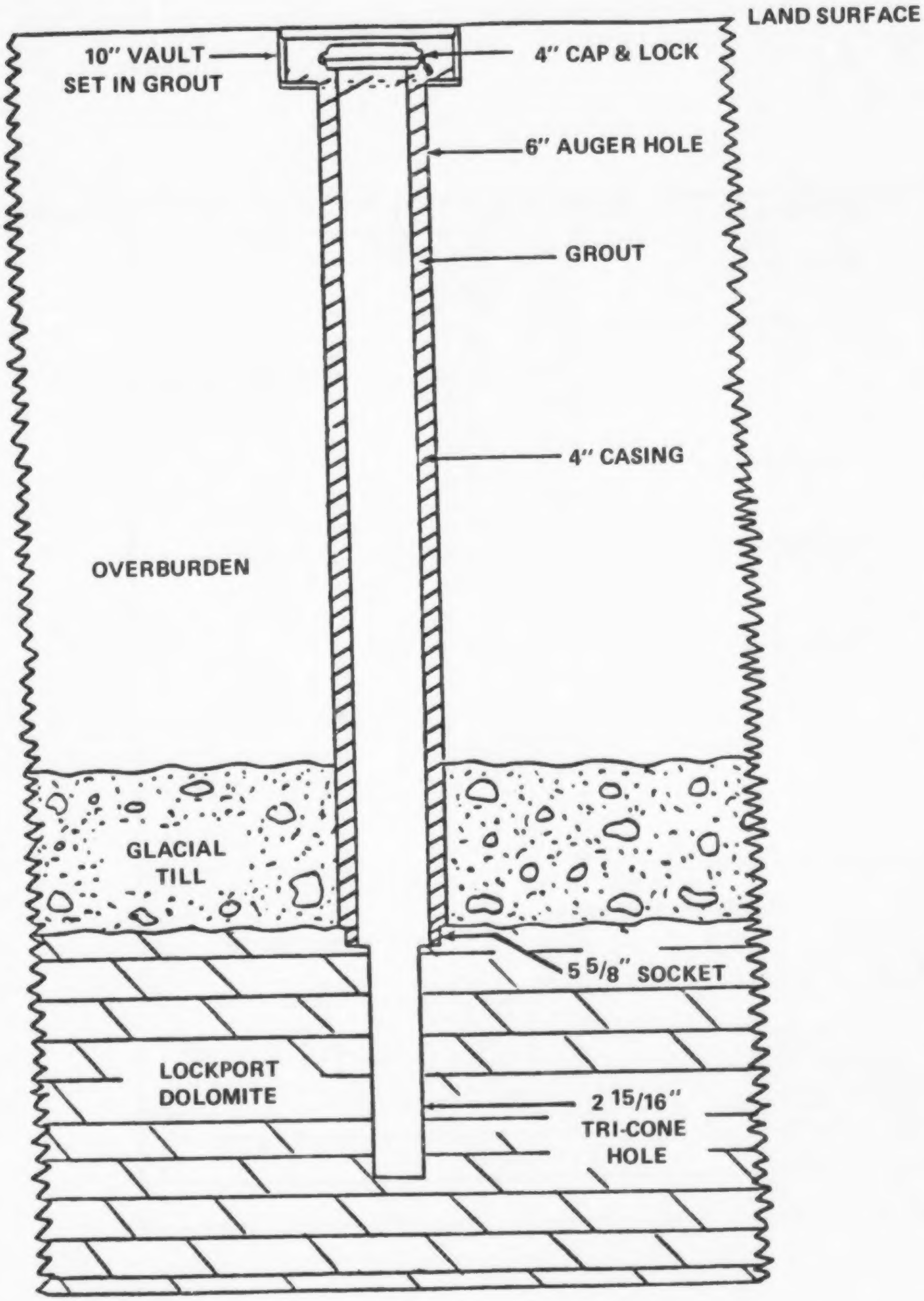

LAND SURFACE
10" VAULT SET IN GROUT
4" CAP & LOCK
6" AUGER HOLE
GROUT
4" CASING
OVERBURDEN
GLACIAL TILL
5 5/8" SOCKET
LOCKPORT DOLOMITE
2 15/16" TRI-CONE HOLE

Figure 16. Completed Bedrock Well.

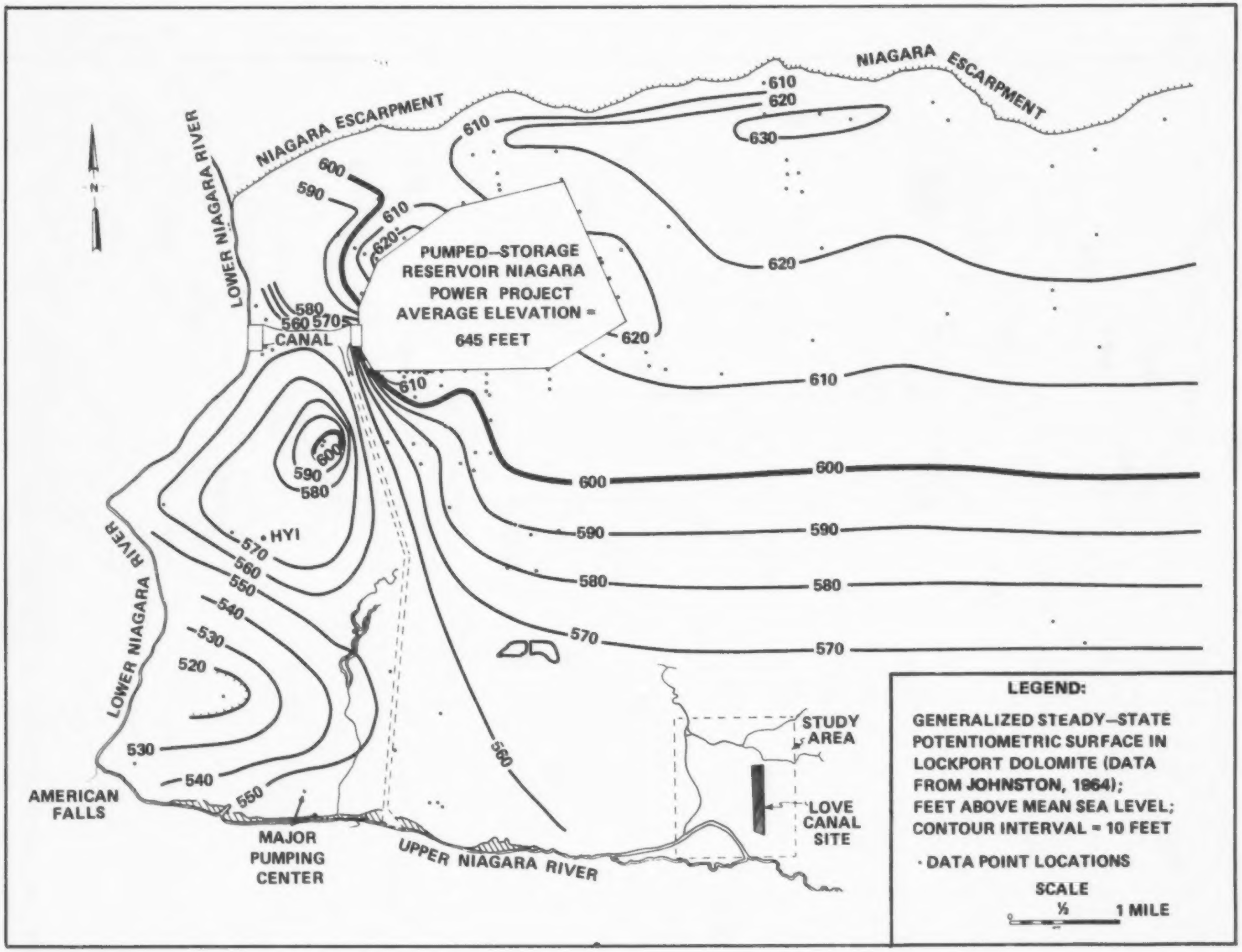
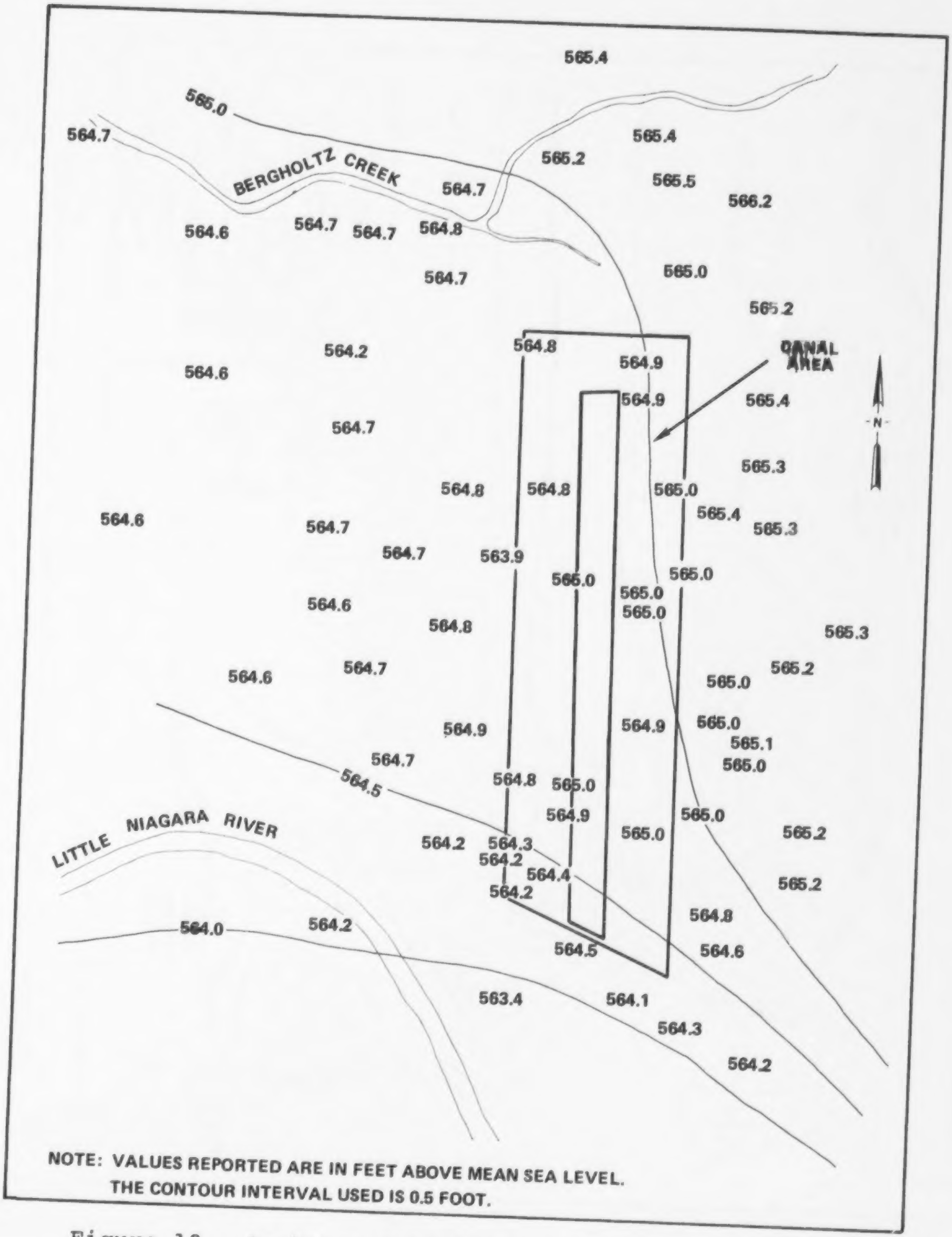

N
NIAGARA ESCARPMENT
NIAGARA ESCARPMENT
LOWER NIAGARA RIVER
LOWER NIAGARA RIVER
UPPER NIAGARA RIVER
AMERICAN FALLS
MAJOR PUMPING CENTER
CANAL
HYI
PUMPED–STORAGE RESERVOIR NIAGARA POWER PROJECT AVERAGE ELEVATION = 645 FEET
STUDY AREA
LOVE CANAL SITE
630
620
610
600
590
580
570
560
550
540
530
520
LEGEND:
GENERALIZED STEADY–STATE POTENTIOMETRIC SURFACE IN LOCKPORT DOLOMITE (DATA FROM JOHNSTON, 1964); FEET ABOVE MEAN SEA LEVEL; CONTOUR INTERVAL = 10 FEET
· DATA POINT LOCATIONS
SCALE
0
½
1 MILE

Figure 17. Regional Lockport Dolomite Potentiometric Surface.


565.4
565.0
564.7
BERGHOLTZ CREEK
565.4
565.2
564.7
565.5
566.2
564.6
564.7
564.7
564.8
564.7
565.0
565.2
564.8
564.2
CANAL AREA
564.6
564.9
564.9
565.4
N
564.7
565.3
564.8
564.8
565.0
564.6
565.4
565.3
564.7
564.7
563.9
565.0
565.0
565.0
565.0
564.6
564.8
565.3
564.6
564.7
565.2
565.0
564.9
564.9
565.0
565.1
565.0
564.7
564.5
564.8
565.0
564.9
565.0
565.0
565.2
LITTLE NIAGARA RIVER
564.2
564.3
564.2
564.4
564.2
565.2
564.0
564.2
564.8
564.5
564.6
563.4
564.1
564.3
564.2

NOTE: VALUES REPORTED ARE IN FEET ABOVE MEAN SEA LEVEL.
THE CONTOUR INTERVAL USED IS 0.5 FOOT.

Figure 18. Lockport Dolomite Potentiometric Surface.

existed in the shallow system. Due to the generally low permeability of overburden materials and the relatively short period of time for field measurement of water level elevations, the surface presented should be interpreted with considerable caution. Even though the surface may only approximate a steady-state at one particular point in time, some general trends can be noted. As may be seen in the illustration, the water surface elevations suggest a general southwesterly gradient with a possible ground-water mound near the north end of the landfill and a slight depression near the south end of the landfill. As a result of a broken water line on 97th Street (located near the intersection of 96th Street with 97th Street between Colvin Boulevard and Read Avenue), which remained unrepaired for a number of weeks during the latter part of the study period, the observed slight ground-water mound near the northern portion of the canal probably signifies that the shallow system had not yet fully returned to equilibrium at the time of water-level measurements in that general vicinity. The slight ground-water depression near the southern end of the landfill was probably caused by the remedial measures instituted at Love Canal.

In most locations, the computed hydraulic head of the shallow system was found to be nearly equal to the hydraulic head in the dolomite. Therefore, it is likely that the hydraulic heads measured in the shallow system are dependent on highly local variations in permeability, in recharge, in evapotranspiration, and in discharge to the creeks and rivers. These factors probably help to account for the features noted in the figure. Due to the low permeability and heterogeneous nature of the overburden, ground-water movement in the overburden is generally very slow except in highly localized areas of more permeable material.

4.1.3.2 Ground-Water Flow Modeling

An extensive report on the modeling of ground-water movement in the general Love Canal area was mentioned earlier as being available from NTIS. Some of the major findings from the modeling effort are restated here.

1. In the general Love Canal area the vertical movement through the confining bed separating the overburden and dolomite aquifers is very low with vertical velocities on the order of 0.001 inches/year.

2. Assuming a downward movement through the confining bed (although the heads probably fluctuate seasonally), and that the confining bed was not breached during excavation and does not contain fracture zones, it would take a non-attenuated contaminant hundreds to thousands of years to migrate down to the dolomite. If attenuation occurs, as is likely, travel time will increase.

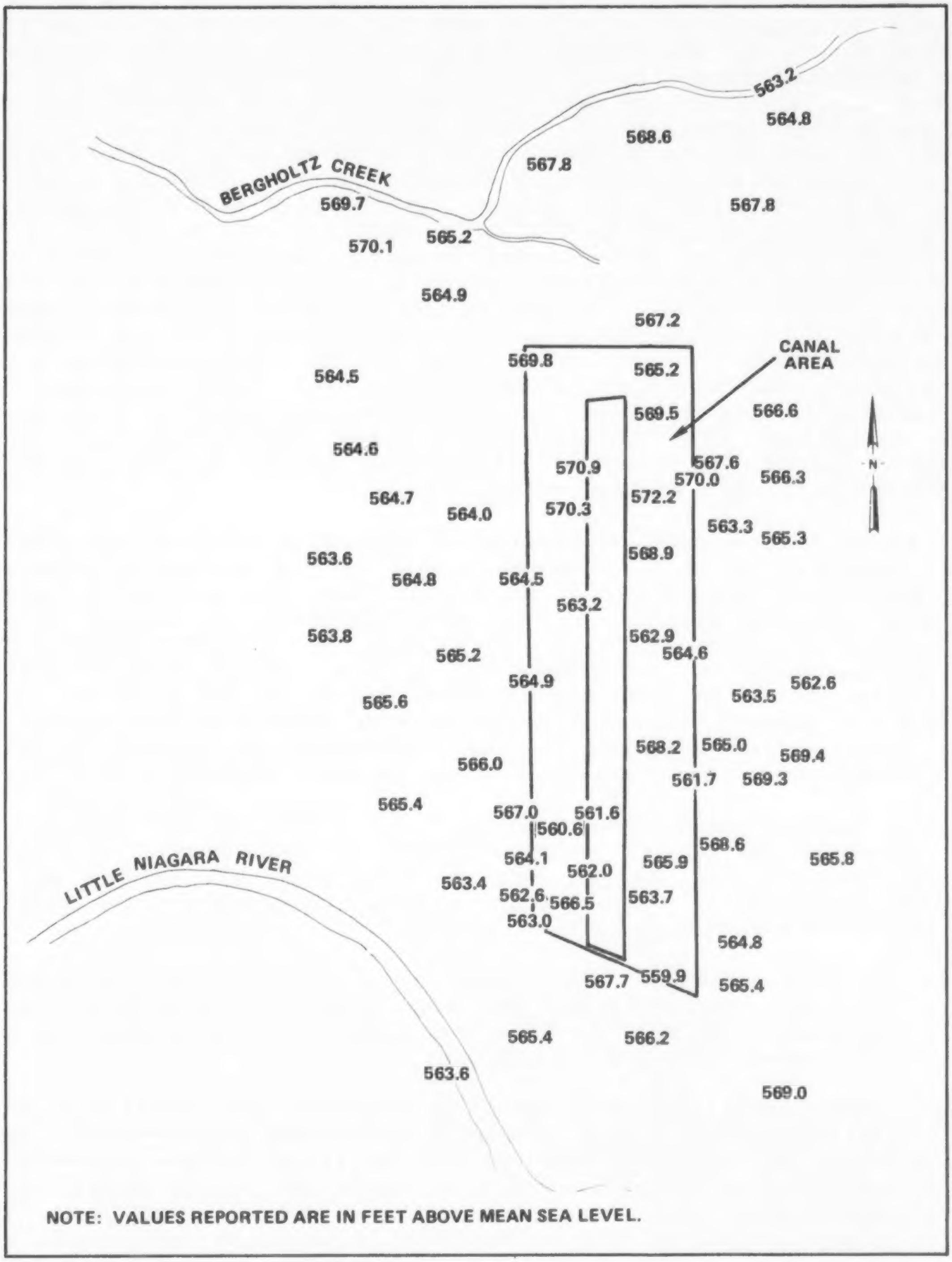

563.2
564.8
568.6
567.8
BERGHOLTZ CREEK
569.7
567.8
570.1
565.2
564.9
567.2
CANAL AREA
569.8
565.2
564.5
569.5
566.6
N
564.6
567.6
570.9
570.0
566.3
564.7
572.2
564.0
570.3
563.3
565.3
563.6
568.9
564.8
564.5
563.2
563.8
562.9
564.6
565.2
564.9
562.6
563.5
565.6
568.2
565.0
569.4
566.0
561.7
569.3
565.4
567.0
561.6
560.6
568.6
LITTLE NIAGARA RIVER
564.1
565.9
565.8
563.4
562.0
562.6
566.5
563.7
563.0
564.8
567.7
559.9
565.4
565.4
566.2
563.6
569.0
NOTE: VALUES REPORTED ARE IN FEET ABOVE MEAN SEA LEVEL.

Figure 19. Overburden Static Water Table.

3. It was estimated that ground water could migrate through the overburden at rates ranging from up to approximately 1 foot/year in the less permeable material, to up to approximately 60 feet/year in the more permeable material. However, due to the discontinuous and heterogeneous nature of the overburden material, the potential attenuation of organic contaminants in clayey soils, and the construction of sewer systems virtually around the entire landfill, it is highly unlikely that contaminated shallow system ground-water migrated beyond ring 1 houses.

4. Selective contamination of certain ring 1 houses by ground-water movement prior to remedial construction was likely to have occurred as a function of random deposits of more permeable material in the overburden (for example, sand lenses and filled swales), and man-made construction activities (for example, a backyard catch basin and drainage pipe); overland flow of contaminants to certain ring 1 houses was a likely mechanism of transport prior to remedial construction when pools of surfaced chemicals were present at the site.

5. The barrier drain system installed around the landfill was found to be an effective remedial measure to contain the outward migration of Love Canal contaminants in the shallow system. The barrier drain system will also cause most shallow system ground water that may have migrated from the landfill over the past 30 years to locations outside the barrier drain system (through relatively high permeability soil pathways), to flow towards the drain system for eventual collection and subsequent treatment in the Leachate Treatment Facility.

4.1.4 Implications of the Hydrogeologic Program Findings

The implications of the hydrogeologic program findings are of significant importance in understanding the extent and nature of the environmental contamination problems at Love Canal. Historically speaking, it is clear that contamination of the environment occurred in the area immediately surrounding the former canal. Prior to remedial construction, local residents were subjected to potential exposure to Love Canal contaminants from a variety of environmental sources: (1) the overland flow of chemicals that formed in pools around the site; (2) the volatilization and airborne transport of surfaced contaminants; and (3) the highly selective ground-water transport of contaminants from the former canal to certain ring 1 houses.

Furthermore, it is clear that (prior to remedial construction) contamination had entered nearby buried utilities and had probably been transported considerable distances from the former canal. In particular, transport occurred through the storm sewer lines around Love Canal, which subsequently contributed to the contamination of local creeks and rivers by virtue of their discharge into those waterways. The historically active mechanisms that likely contributed to storm sewer contamination were noted previously as including: (1) the collection of surfaced contaminants which were transported by precipitation run-off to curb drains surrounding the site; (2) the infiltration of contaminants into storm sewer lines located adjacent to the landfill (for example, ground-water transport may have occurred more readily to the laterals on Read and Wheatfield Avenues and through specific permeable soil pathways to storm sewer lines on 97th and 99th Streets); (3) the discharge to storm sewers of contaminants taken-up by sumps in certain ring 1 houses that had been subjected to contamination by ground-water transport and/or overland flow; (4) the discharge of contaminants taken-up by the French drain surrounding the 99th Street Elementary School; and (5) the infiltration and collection of surfaced contaminants in the catch basin located near the landfill at 949-953 97th Street. As a result of remedial actions conducted at the site during 1978 and 1979, it is likely that only residual contamination remains in the nearby sewer systems.

Based on the findings of the hydrogeologic program, the following implications are offered regarding the likely extent and degree of environmental contamination at Love Canal.

1. Contamination in the shallow system will likely be confined primarily to the Canal Area, with contamination movement occurring selectively along discontinuous, more permeable, soil pathways.

2. Contamination in the bedrock aquifer (directly attributable to Love Canal) is not likely, unless the glacial till was breached during excavation activities.

3. Contamination of other environmental media is highly unlikely outside of ring 1, except as impacted by storm sewer transport of contaminants.

4. Contaminated soil, directly attributable to the migration of contaminants from Love Canal, will likely be present only in ring 1. Contamination in soil will likely be greatest where both overland flow and ground-water transport contributed to the migration of contaminants from the former canal. (From historical evidence and the direction of ground-water movement, contaminated soil is likely to be higher south of Wheatfield Avenue, and probably on the 97th Street side, than elsewhere). Contaminated soil outside of ring 1, if found, probably resulted from other causes or from use of contaminated fill materials (that is, it is unlikely to be related directly to Love Canal).

5. Contaminated sumps, directly attributable to the migration of contaminants from Love Canal, will likely be present only in certain ring 1 houses where soil conditions permitted the more ready ground-water transport of contaminants. As a result of ground-water flow patterns, contamination in sumps is likely to be higher on the southwestern side (97th Street south of Wheatfield Avenue) of Love Canal than elsewhere.

6. Contamination is likely present in storm sewers and in area creeks and rivers near storm sewer outfalls, and is likely to be residual (prior to remedial construction) contamination. As a result of likely transport mechanisms that were operative prior to remedial construction, contamination will probably be higher in storm sewer lines on 97th Street, and in area waterways near outfalls fed by the 97th Street storm sewer line, than elsewhere.

7. Because the majority of organic compounds deposited in Love Canal are attenuated by clay (as opposed to being in aqueous solution), ground-water transport and other waterborne transport will likely be retarded. As a result, collocated water and sediment samples will likely reveal higher levels of contamination in the sediment than in the water (when contamination is present).

8. Because the former canal has been capped since 1979, which has altered the hydrogeological characteristics of the landfill, contamination in air directly attributable to Love Canal will likely not be present in the Declaration Area. It is likely that only certain, selectively contaminated ring 1 residences will display evidence of air contamination that is directly attributable to Love Canal, and incrementally significant above background. Furthermore, it is likely that air contamination in the vast majority of ring 1 residences was terminated in 1979, as a result of the completion of remedial actions at the site and the simultaneous cessation of sump pumps operating in Canal Area residences in 1979.

4.2 EVIDENCE OF CONTAMINATION MOVEMENT

The monitoring efforts at Love Canal were conducted by EPA to obtain evidence regarding the migration of contaminants from the former canal into the surrounding Declaration Area. The results of these studies are presented in this section of the report. In Table 6, a summary of the magnitude of the multimedia monitoring efforts designed to identify evidence of chemicals migrating from Love Canal is presented. The data in Table 6 enumerate for each medium/source/location sampling combination the total number of analytes determinations, the number of samples analyzed (note that this number does not necessarily refer to the number of

TABLE 6. FREQUENCY OF DETECTION OF CONTAMINANTS IN VALIDATED LOVE CANAL SAMPLES

	Declaration Area		Control		Canal Area	
Medium/Source/ Location	Determinations† (Samples)	Percent Detect	Determinations (Samples)	Percent Detect	Determinations (Samples)	Percent Detect
Ground Water						
Shallow	6,675 (233)	8.5	1,580 (55)	9.0	2,438 (81)	10.6
Bedrock	4,966 (179)	8.4	2,688 (94)	8.5	1,859 (67)	6.2
Soil	22,361 (753)	9.4	1,607 (57)	9.7	4,442 (158)	10.4
Sump Water	18,752 (694)	10.2	650 (23)	10.2	2,432 (97)	14.4
Sump Sediment	0 (0)	--	0 (0)	--	159 (6)	36.5
Sanitary Sewer Water	152 (6)	22.4	0 (0)	--	0 (0)	--
Sanitary Sewer Sediment	74 (1)	62.6	0 (0)	--	0 (0)	--
Storm Sewer Water	1,612 (87)	8.3	142 (5)	3.5	344 (17)	10.2
Storm Sewer Sediment	2,399 (116)	15.5	76 (2)	18.4	637 (28)	28.3
Surface Water	2,268 (84)	7.1	727 (28)	5.8	0 (0)	--
Stream Sediment	2,538 (79)	21.3	746 (22)	14.6	0 (0)	--
Air						
HIVOL	1,088 (109)	45.3	0 (0)	--	89 (9)	41.6
PFOAM	10,865 (636)	6.3	541 (32)	6.1	1,232 (74)	6.3
TENAX	21,082 (896)	36.5	791 (34)	40.2	2,006 (108)	36.3

†Total number of specifically targeted chemicals analyzed for in all combined validated samples

Note: Inorganic substances represent approximately the following percent of the determinations in the medium/source identified: water, 9; sediment, 9; soil, 9; and HIVOL, 100.

sites sampled), and the percent of the analytes determinations that were identified at a trace or greater concentration. (See Appendixes C through E of this Volume for information on analytical limits of detection).

The relatively large number of substances monitored at Love Canal possess a wide range of physical and chemical properties that are associated with their potential for migrating from the former canal. In particular, the substances monitored vary considerably in terms of solubility, vapor pressure, and sorbtive behavior; characteristics that are commonly used to indicate the potential mobility of a chemical in the environment. Based on these characteristics, the targeted substances include chemicals that are expected to vary in potential mobility from (relatively) high to low. As a consequence of the relatively wide range of chemical and physical properties possessed by the substances monitored, the likelihood of detecting the presence of Love Canal-related contamination in the Declaration Area was increased. Because the targeted substances also represented those that were most abundant in the source, prevalent in the environment, and of toxicological concern, and because purposive sampling was employed along suspected pathways of contaminant transport, it is highly unlikely that the presence of substantial amounts of Love Canal-related contamination in the Declaration Area would have been missed by the monitoring program.

In the sections that follow the results from the monitoring program conducted at Love Canal are presented. It should be noted that while all of the monitoring results were considered in the statements of findings, only a relatively limited number of substances are presented for discussion purposes. To the extent possible, a consistent set of chemicals are discussed across all medium/source/location combinations in order to provide continuity and comparability to the findings.

4.2.1 Ground-Water Contamination

Evidence of contaminant movement in ground water was obtained through the installation (described previously) and sampling of a large number of monitoring wells throughout the general Love Canal area. Ground-water contamination was monitored separately in the overburden shallow system (A Wells) and in the bedrock aquifer (B Wells). The findings from these monitoring efforts are described sequentially. It should be noted that no ground-water monitoring wells were installed inside the boundary of the barrier drain system encircling the former canal.

4.2.1.1 Shallow System

In general, neither the extent (that is, the relative frequency with which substances were detected at a trace or greater concentration) nor the degree (the value of the median concentration measurement for a particular substance) of contamination in the Declaration Area differed significantly ($\alpha = 0.10$, one-tailed) from the ground-water contamination observed at shallow system control sites. Statistically significant differences in the extent of shallow system ground-water contamination, based on comparisons between the Canal Area and Declaration Area, were found for the substances identified in Table 7. (See Volume III for additional details). Note, that the results of the statistical tests reported in Table 7 (and in similar subsequent tables) are not pair-wise independent. Consequently, the Type I error rate (that is, the probability of incorrectly rejecting the null hypothesis) is greater than α.

As can be seen from the data summarized in Table 7, and presented in detail in Volume III, virtually no evidence of shallow system ground-water contamination was found at sites sampled outside the Canal Area. The absence of Declaration Area shallow system ground-water contamination, that was directly attributable to the migration of contaminants from the former canal, conformed to the findings and implications of the hydrogeologic program. Specifically, the data revealed that contamination of the overburden aquifer was confined to the Canal Area, and that within the Canal Area only selective migration (along more permeable soil pathways) of contaminants from Love Canal had occurred.

Three examples of typical shallow system findings are presented in Figures 20 through 22 to illustrate the overburden ground-water contamination observed at Love Canal. Additional figures are included in Volume III. The results presented in Figures 20 through 22 are for benzene, toluene, and γ-BHC (Lindane), respectively. These compounds were selected for presentation because of their migration properties and because they were illustrative of shallow system findings, were among the most frequently detected organic compounds in the shallow system, and were known waste materials deposited in the former canal. In Figures 20 through 22, the maximum concentration of the compound of interest observed at each site is presented. This procedure was adopted in order to incorporate the information obtained at those QA/QC sites where multiple field samples may have been collected. Consequently, the concentration levels presented in these figures are likely to be conservative (that is, high) indicators of the actual concentration levels present in the shallow system ground water at those sites sampled. Note that in all figures no systematic evidence was observed of contaminants that had migrated from Love Canal into the Declaration Area, even though numerous wells were sited in the Declaration Area along suspected transport pathways (for example, in or near former swales).

Additional detailed analyses of the shallow system monitoring data (using a variety of statistical methods such as correlational analysis, principal components analysis, and cluster analysis--see, for example, S. James Press, Applied Multivariate

TABLE 7. SIGNIFICANT DIFFERENCES OBSERVED IN EXTENT OF SHALLOW SYSTEM GROUND-WATER CONTAMINATION AT LOVE CANAL

	Percent Detect (Number of Samples)			Comparison[†]	
Compound/Element	Decl.	Control	Canal	Canal - Decl.	Decl. - Control
2,4-Dichlorophenol	2.1 (47)	9.1 (11)	18.8 (16)	Yes	No
2,4,6-Trichlorophenol	0.0 (47)	0.0 (11)	13.3 (15)	Yes	No
1,4-Dichlorobenzene	0.0 (47)	0.0 (11)	12.5 (16)	Yes	No
1,2-Dichlorobenzene	0.0 (47)	0.0 (11)	12.5 (16)	Yes	No
1,2,4-Trichlorobenzene	0.0 (47)	0.0 (11)	12.5 (16)	Yes	No
1,2,3,4-Tetrachlorobenzene	0.0 (47)	0.0 (11)	12.5 (16)	Yes	No
Acenaphthylene	4.3 (47)	0.0 (11)	18.8 (16)	Yes	No
Fluorene	4.3 (47)	0.0 (11)	18.8 (16)	Yes	No
1,1-Dichlorethene	2.3 (43)	0.0 (11)	14.3 (21)	Yes	No
Tetrachloroethene	2.3 (43)	27.3 (11)	19.0 (21)	Yes	No
2-Chlorotoluene	0.0 (43)	0.0 (11)	19.0 (21)	Yes	No
3-Chlorotoluene	0.0 (43)	9.1 (11)	10.0 (20)	Yes	No
4-Chlorotoluene	0.0 (43)	0.0 (11)	9.5 (21)	No (α=0.104)	No
Chlorobenzene	2.3 (43)	0.0 (11)	23.8 (21)	Yes	No
Chromium	66.0 (43)	70.0 (10)	92.9 (14)	Yes	No
Lead	72.3 (47)	77.8 (9)	100.0 (13)	Yes	No

[†] Comparisons based on a one-tailed difference of proportions test (α=0.10), using Fisher's exact test, for the areas indicated, and in the order presented.

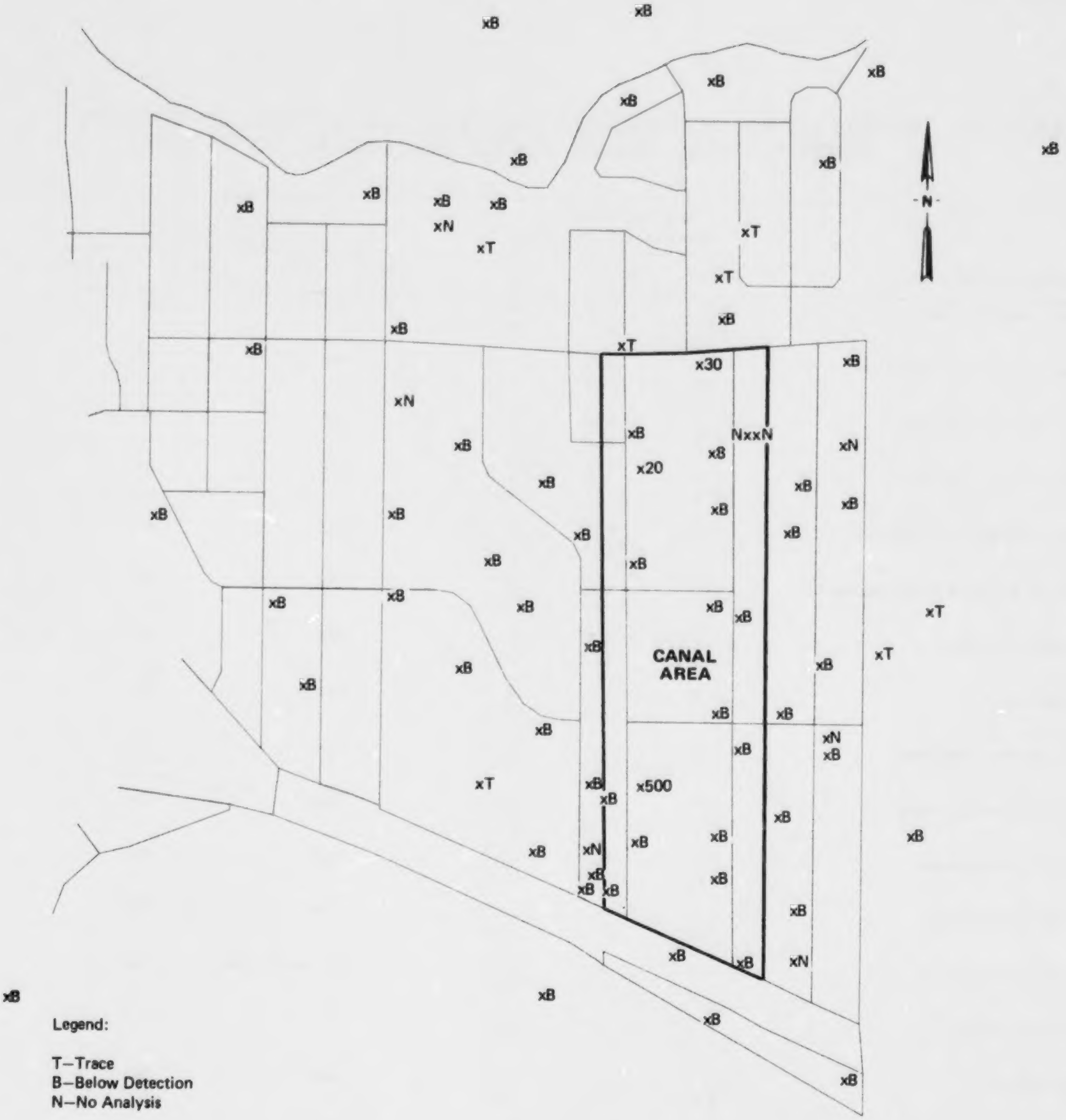

xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xN
xT
xT
xT
xB
xB
xT
xB
x30
xB
xN
xB
NxxN
xB
xN
x20
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xT
xB
xB
xB
xB
xB
xB
CANAL AREA
xT
xB
xB
xB
xB
xB
xB
xN
xB
xB
xT
xB
x500
xB
xB
xB
xB
xN
xB
xB
xB
xB
xB
xB
xB
xB
xB
xN
xB
xB
xB
xB
N
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 20. Well A Sampling Sites, Benzene, Maximum Concentrations (micrograms per liter, ppb).

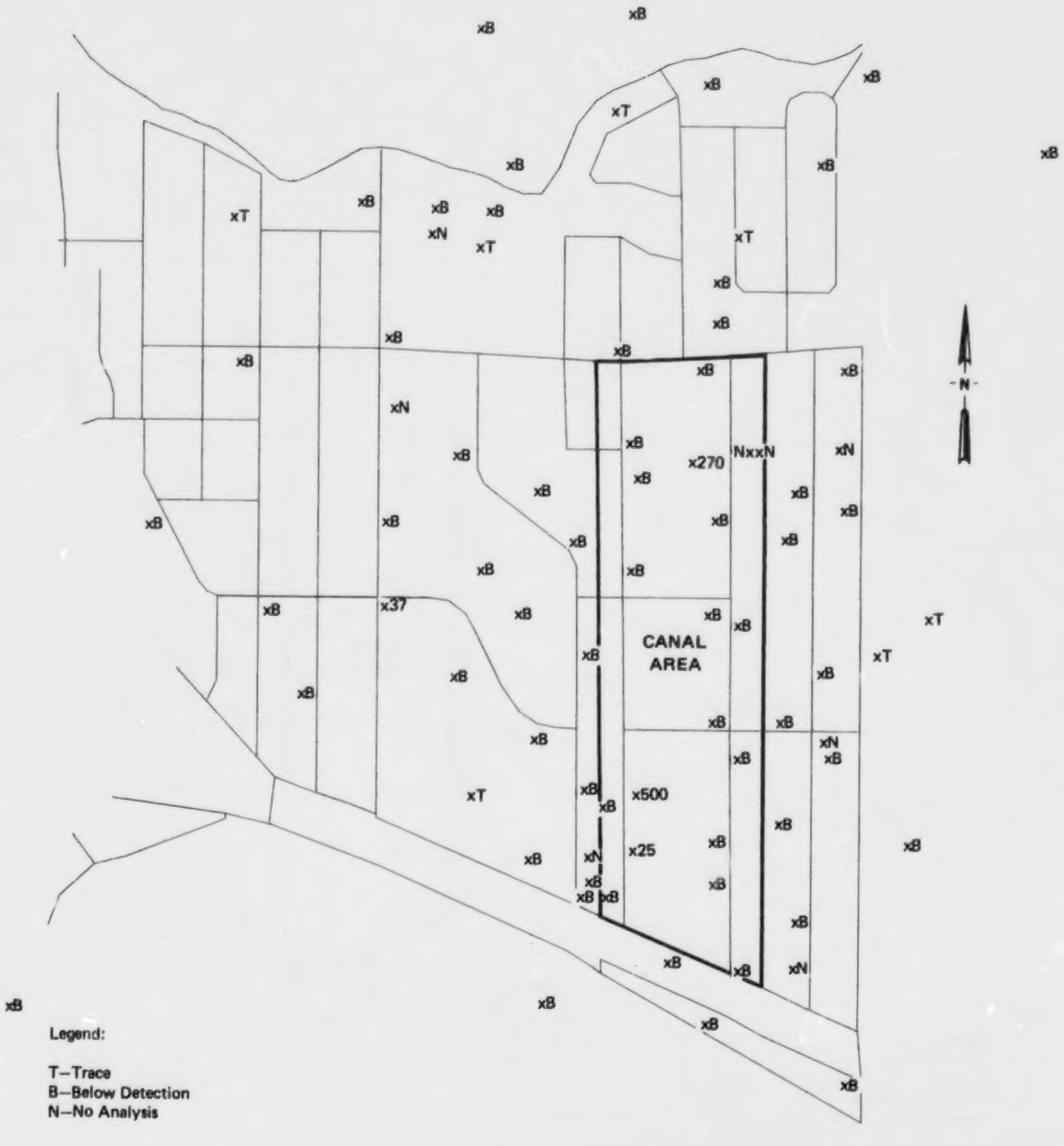

xB
xB
xB
xB
xT
xB
xB
xB
xB
xT
xB
xB
xN
xT
xT
xB
xB
xB
xB
xB
xB
xB
N
xN
xB
xB
x270
NxxN
xN
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
x37
xB
xB
xB
xB
xT
CANAL
AREA
xB
xT
xB
xB
xB
xB
xB
xB
xN
xB
xB
xB
xB
xT
x500
xB
xB
xB
xB
x25
xN
xB
xB
xB
xB
xB
xB
xB
xB
xN
xB
xB
xB
xB
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 21. Well A Sampling Sites, Toluene, Maximum Concentrations (micrograms per liter, ppb).

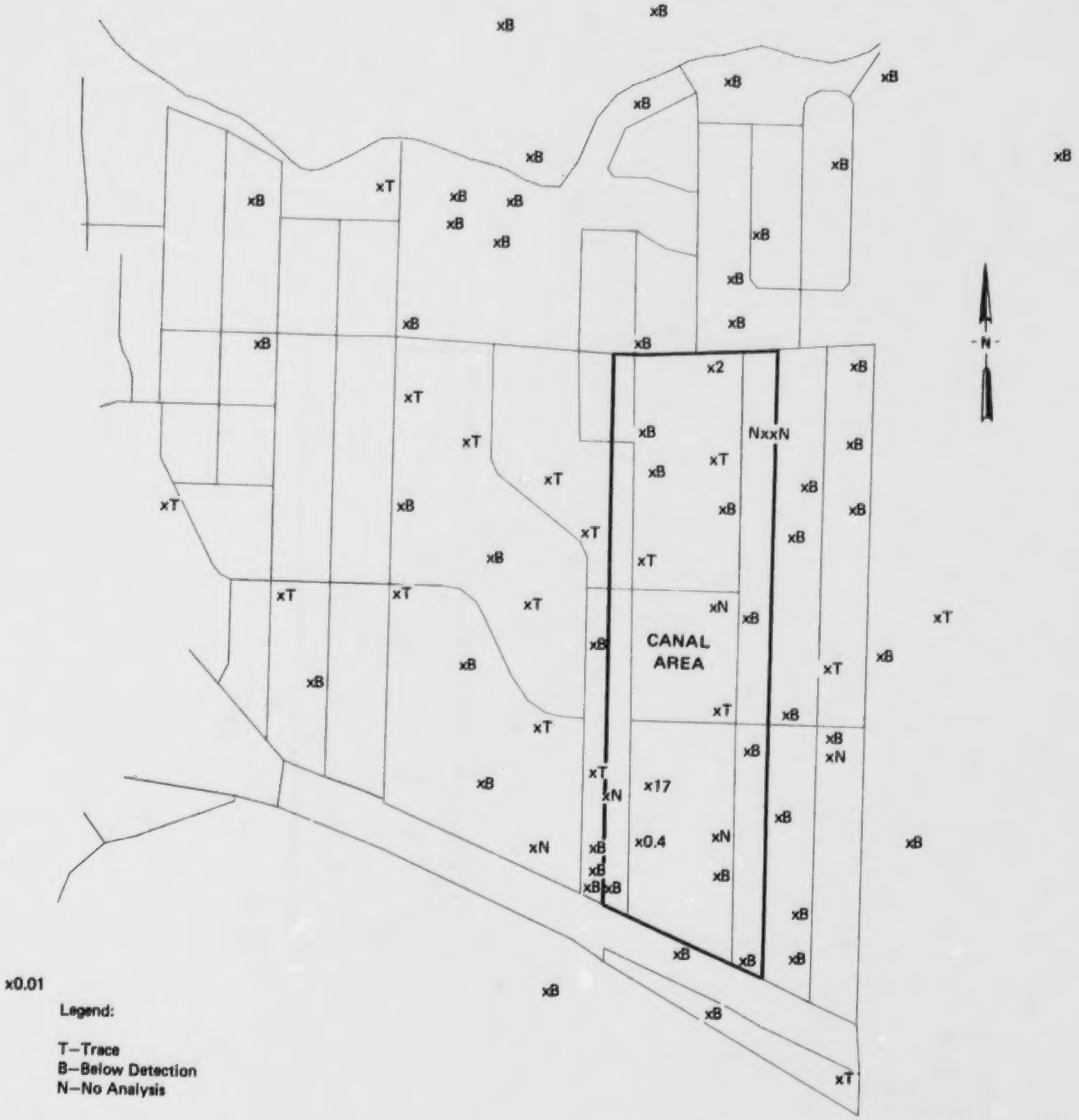

xB
xB
xB
xB
xB
xB
xB
xB
xT
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
x2
xB
xT
xT
xB
NxxN
xB
xB
xT
xT
xB
xT
xB
xB
xB
xT
xB
xB
xT
xT
xT
xT
xN
xB
xT
xB
CANAL AREA
xB
xT
xB
xB
xT
xB
xT
xB
xB
xN
xT
x17
xB
xN
xB
xN
xB
x0.4
xN
xB
xB
xB
xB xB
xB
xB
xB
xB
x0.01
xB
xB
xT
Legend:
T—Trace
B—Below Detection
N—No Analysis
N

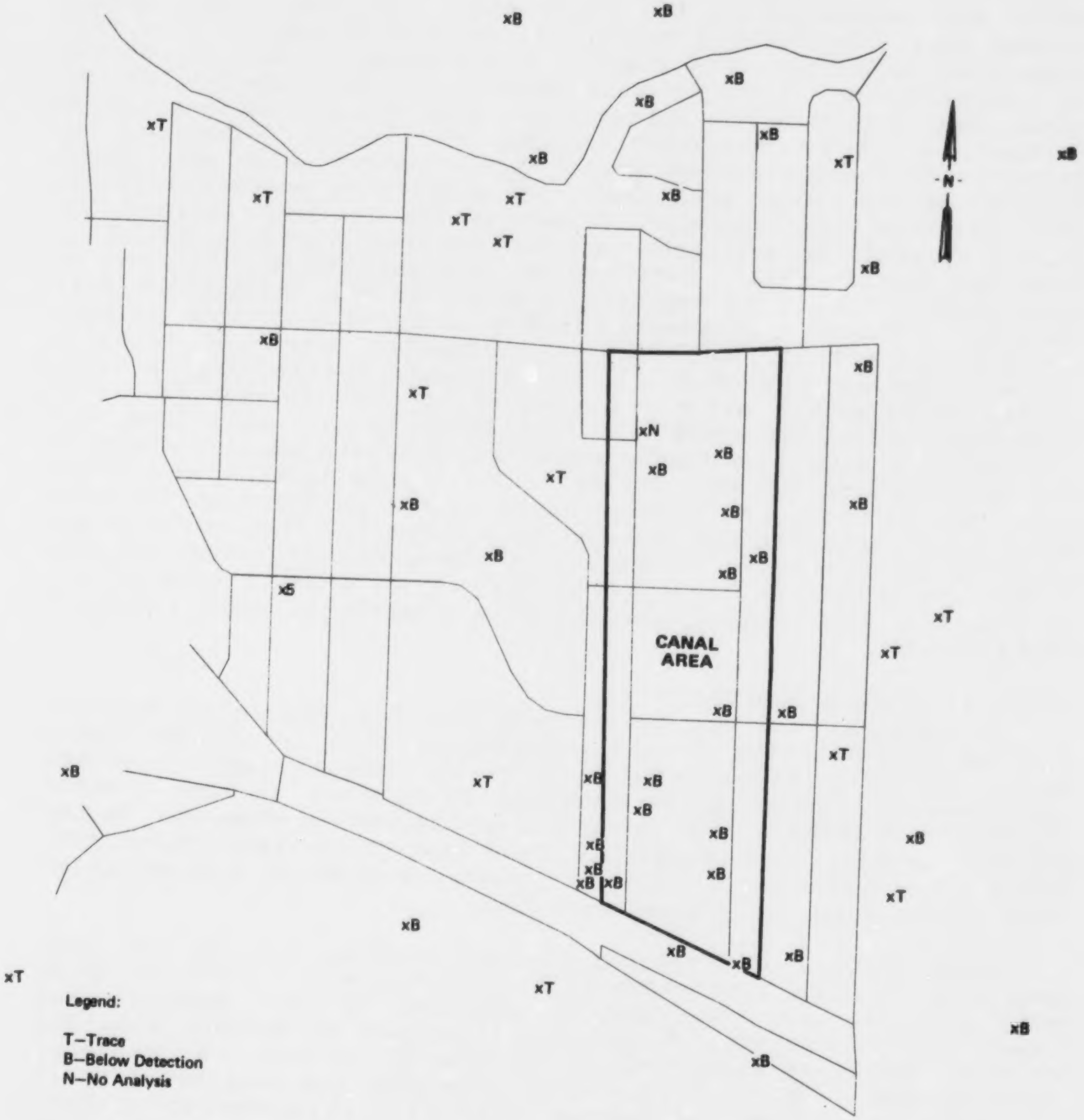
Figure 22. Well A Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per liter, ppb).

Analysis, Holt, Rinehart and Winston, 1972), revealed that contamination by organic compounds in the shallow system ground water was restricted to the Canal Area. In fact, the results showed that only three A Wells, all located within ring 1, were highly contaminated. The results also suggested that no pattern of contamination, directly attributable to the migration of organic compounds from the former canal into the surrounding neighborhood, could be discerned outside of ring 1. That is, no patterns of shallow system ground-water contamination were found outside of the Canal Area that corresponded to suspected transport pathways (for example, former swales or sand lenses), or that indicated the existence of concentration gradients emanating from the former canal. Furthermore, the infrequent detection of quantifiable levels of organic compounds in the Declaration Area occurred ordinarily as geographically isolated instances of contamination, and did not display systematic detection patterns across compounds. Because all three highly contaminated shallow system ground-water sites are located on what is now NYS-owned property, their addresses are identified here: well 104A was located in a suspected former swale and near the barrier drain in the lot south of 754 99th Street; well 77A was located in a known sand lens and near the barrier drain in the backyard of 775 97th Street; and well 75A was located in a suspected former swale and near the barrier drain in the lot at the southwest corner of 99th Street and Colvin Boulevard. A total of 46 A Wells (out of the 79 sampled) had organic contaminants present at only trace or lower levels.

4.2.1.2 Bedrock Aquifer

In general, neither the extent nor the degree of bedrock aquifer contamination in the Declaration Area (or in the Canal Area) differed significantly ($\alpha = 0.10$, one-tailed) from the ground-water contamination observed at bedrock aquifer control sites. Furthermore, the levels of contamination observed in the bedrock aquifer were generally very low, displayed random patterns of occurrence, and did not reveal plumes of contamination that directly emanated from Love Canal.

Three examples of typical bedrock aquifer results are presented in Figures 23 through 25 to illustrate the Lockport Dolomite ground-water contamination observed in the general Love Canal area (additional figures are included in Volume III). The organic compounds displayed in Figures 23 through 25, benzene, toluene, and γ-BHC (respectively), were selected because of their migration properties and because they were illustrative of bedrock aquifer findings, were among the most frequently detected compounds in the bedrock aquifer, and were known waste materials present in the landfill. As before, the maximum concentration of the compound of interest observed at each site is presented.



xB
xB
xB
xT
xB
xB
xT
xB
N
xT
xB
xT
xT
xT
xB
xB
xB
xT
xN
xB
xT
xB
xB
xB
xB
xB
xB
xB
x5
xT
CANAL
AREA
xT
xB
xB
xB
xT
xT
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xB
xT
xB
xB
xB
xT
xT
xB
xB
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 23. Well B Sampling Sites,
Benzene, Maximum Concentrations
(micrograms per liter, ppb).

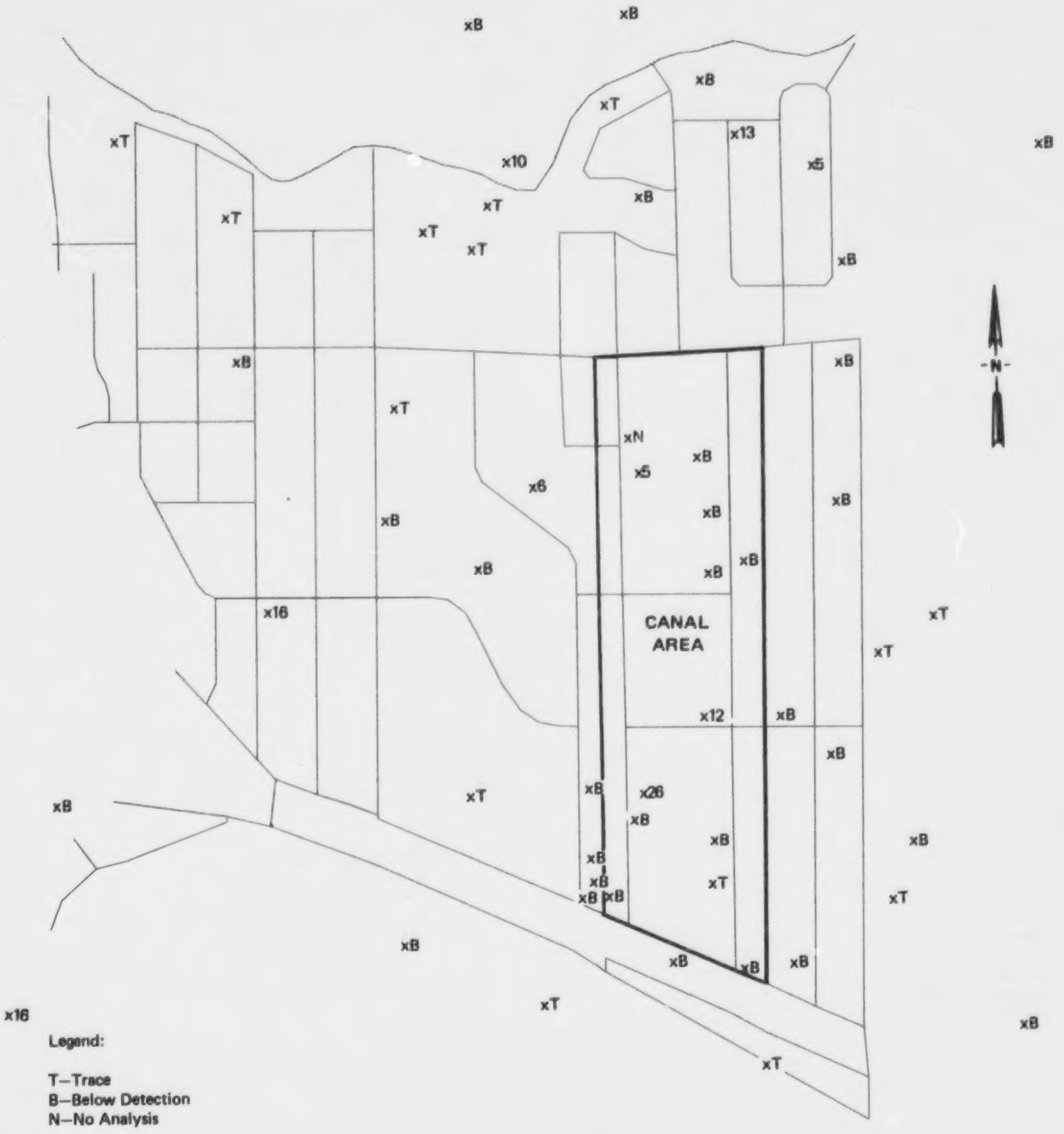

xB
xB
xB
xT
xT
x13
x5
xB
x10
xT
xB
xT
xT
xT
xB
xB
-N-
xB
xT
xN
xB
x5
x6
xB
xB
xB
xB
xB
xB
xB
xT
x16
CANAL AREA
xT
x12
xB
xB
xB
xT
xB
x26
xB
xB
xB
xB
xT
xB xB
xB
xT
xB
xB
xB
xB
xT
x16
xB
xT
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 24. Well B Sampling Sites, Toluene, Maximum Concentrations (micrograms per liter, ppb).

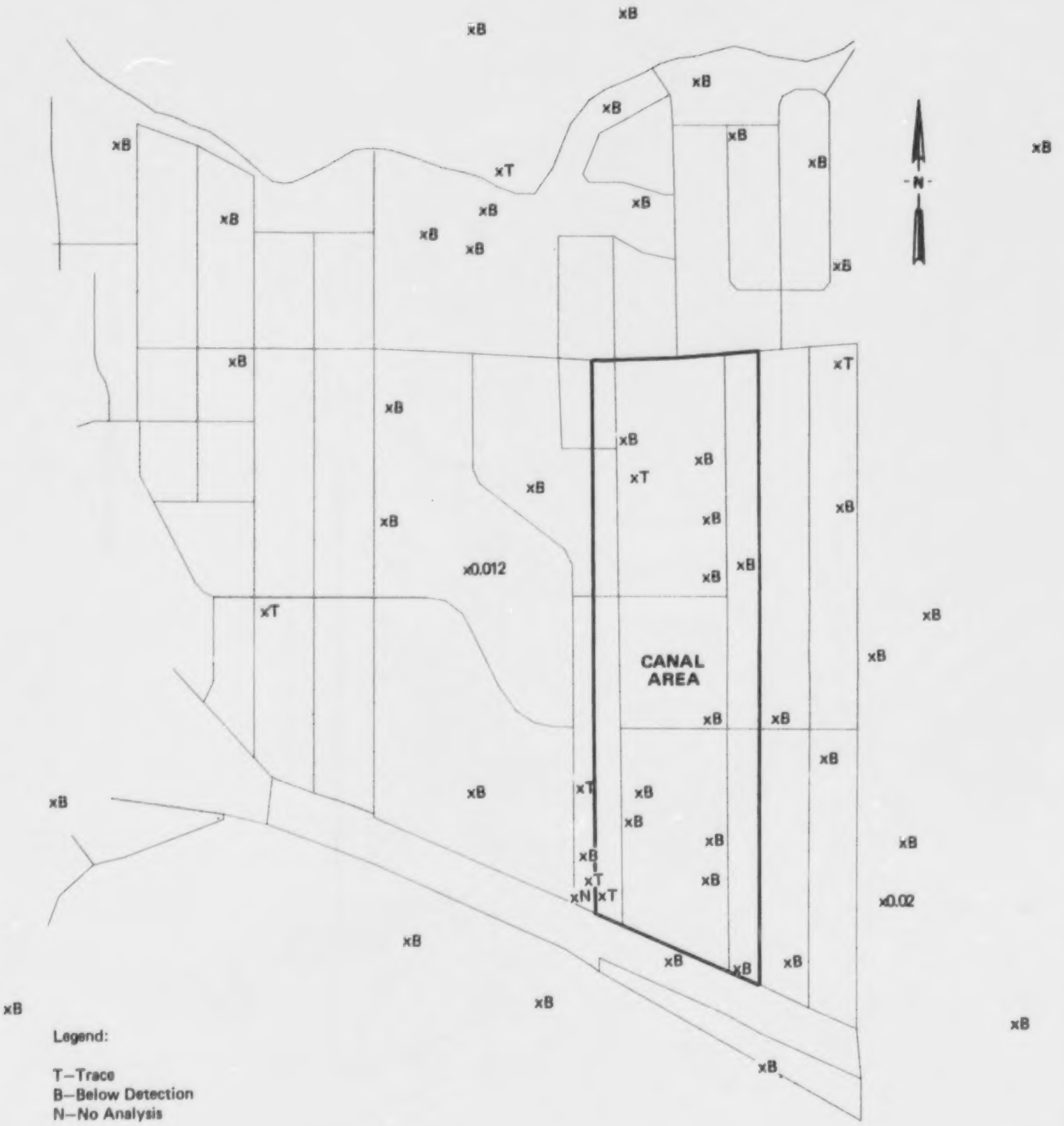

xB
xB
xB
xB
xB
xB
xB
xT
xB
xB
xB
xB
xB
xB
xB
xB
xB
xT
xB
xB
xT
xB
xB
xB
xB
xB
xB
x0.012
xB
xB
xT
xB
CANAL AREA
xB
xB
xB
xB
xT
xB
xB
xB
xB
xB
xB
xT
xN
xT
xB
x0.02
xB
xB
xB
xB
xB
xB
xB
xB
N
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 25. Well B Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per liter, ppb).

It can be seen in Figures 23 through 25 that no clear patterns of Love Canal-related bedrock aquifer contamination were suggested by the data. Rather, the data revealed that very low-level, wide-spread contamination in the bedrock aquifer was likely present, and that the source (or sources) of the contamination observed in the aquifer could not be identified. In particular, the data revealed that anomalous up-gradient contamination was present in the aquifer at substantial distances from Love Canal. The data also suggested that no clear evidence existed of an incremental contribution to bedrock aquifer contamination which could be directly attributed to the migration of contaminants from Love Canal into the aquifer.

The absence of clear, consistent evidence demonstrating the migration of contaminants from the former canal into the bedrock aquifer conforms to the findings of the hydrogeologic program. Furthermore, these findings provide indirect support to the inference that the glacial till under the former canal was not likely breached as a result of excavation or dumping activities.

Additional detailed analyses of the bedrock aquifer monitoring data suggested that the observed low-level organic contamination found in bedrock ground-water samples was both widespread and nonsystematic; that is, contamination was observed up-gradient and at substantial distances from the former canal. In particular, it was observed that all of the bedrock monitoring wells located closest to Love Canal (that is, in the Canal Area) had only low-level organic contamination present (with total concentrations less than 100 parts per billion--micrograms per liter), and that bedrock monitoring wells located in the Canal Area encircled the landfill. Given the southerly direction of ground-water movement in the Lockport Dolomite near Love Canal and the lack of clear evidence of a plume of contamination in the bedrock aquifer that originated in the Canal Area, it is likely that contamination observed in the aquifer was not directly related to the migration of contaminants from Love Canal. A total of 21 B wells (out of the 57 sampled) had organic contaminants present at only trace or lower concentration levels.

4.2.2 Soil Contamination

The extent and degree of soil contamination at Love Canal was determined through the collection of soil samples at 171 sites (Figure 26), and the analysis of those samples for the targeted substances listed in Appendix A. Soil sampling sites were often intentionally located along suspected transport pathways, including former swales, sand lenses, and wet/dry areas. In addition, sites were located at places where residents reported the suspected presence of chemical contamination, the deposition of fill materials thought to have been removed from the Canal Area, or the deposition of fill materials thought to be chemical-industry wastes. Soil samples were also intentionally collected at each

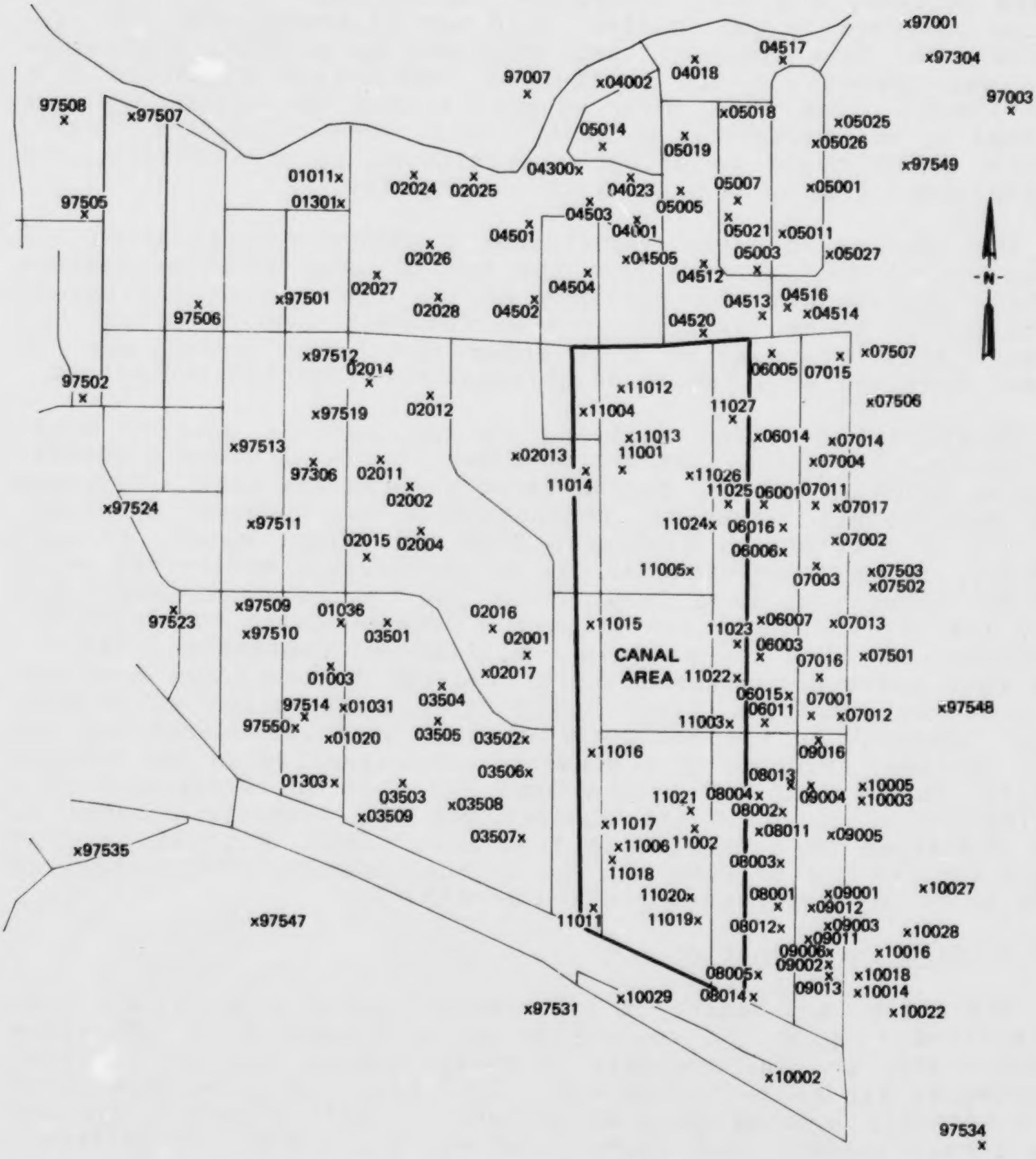

97001
04517
97304
97007
04002
04018
97508
97507
05018
97003
05025
05014
05019
05026
01011
02024
02025
04300
04023
05007
05001
97549
97505
01301
04503
05005
04501
04001
05021
05011
02026
04505
05003
05027
04512
N
97506
97501
02027
02028
04502
04504
04513
04516
04514
04520
97512
02014
06005
07015
07507
97502
11012
11027
07506
97519
02012
11004
11013
06014
07014
97513
02013
11001
07004
97306
02011
11014
11026
02002
11025
06001
07011
07017
97524
97511
11024
06016
07002
02015
02004
06006
11005
07003
07503
07502
97509
01036
02016
11015
11023
06007
07013
97523
97510
03501
02001
06003
07016
07501
CANAL AREA
02017
11022
01003
03504
06015
07001
97548
97514
01031
06011
07012
97550
01020
03505
03502
11003
11016
09016
03506
08013
01303
03503
11021
08004
09004
10005
10003
03508
08002
03509
11017
11002
08011
09005
03507
97535
11006
11018
08003
11020
08001
09001
10027
09012
97547
11011
11019
08012
09003
10028
09011
10016
09006
09002
08005
10018
10029
08014
09013
10014
97531
10022
10002
97534

Figure 26. Soil Sampling Site Codes.

base residence for the purpose of multimedia monitoring. And finally, in order to assure that the soil samples collected adequately represented the entire general Love Canal area, sites throughout the Declaration Area and Canal Area were randomly selected (that is, with equal probability) for sampling. It should also be noted that no soil samples were collected inside the boundary of the barrier drain system encircling the former canal.

Soil sampling at each site was conducted as follows. Because it was not possible to stipulate ahead of time the depth at which contaminants migrating from the landfill might be located in the soil, but with knowledge that the top 6 feet of soil typically included nearly all of the more permeable soil material, it was decided that the entire top 6 feet of soil would be sampled. The device used to sample soil was a truck-mounted soil corer, 6 feet in length and 1 3/8 inches in diameter. Because it was not possible to stipulate ahead of time the likely geographical distribution of contaminants at a given sampling site, it was decided that at each sampling site a total of seven soil cores would be collected. Of the seven soil cores collected at each site, two cores were appropriately handled, and subsequently analyzed separately for volatile organic compounds. The remaining five soil cores were homogenized, and subsequently analyzed for the additional targeted substances of interest. A typical soil sampling scheme employed at Love Canal is presented in Figure 27; note, however, that the actual sampling configuration used at a site was dependent on the size of the area available for sampling.

The results from the soil monitoring program revealed a pattern of Love Canal-related environmental contamination that was consistent with the findings of the hydrogeologic program, and corresponded to the ground-water monitoring findings. In general, the patterns of soil contamination that were observed revealed that contaminants had migrated directly from the former canal to the immediate vicinity of certain ring 1 residences. In particular, evidence of soil contamination that was directly attributable to the migration of contaminants from Love Canal was found near: (1) those ring 1 residences that were suspected of having been subjected to the overland flow of contaminants from the landfill prior to remedial construction; and (2) those ring 1 residences that had been constructed in the vicinity of more permeable soil pathways conveying through-ground migration of contaminants from the landfill prior to remedial construction. A summary of the statistically significant soil monitoring findings is presented in Table 8. Again, recall that the Type I error rate is larger than α.

As can be seen from the results presented in Table 8, and from a review of the detailed tables included in Volume III, the soils monitoring data revealed that Love Canal-related environmental contamination was confined to the Canal Area. Supporting

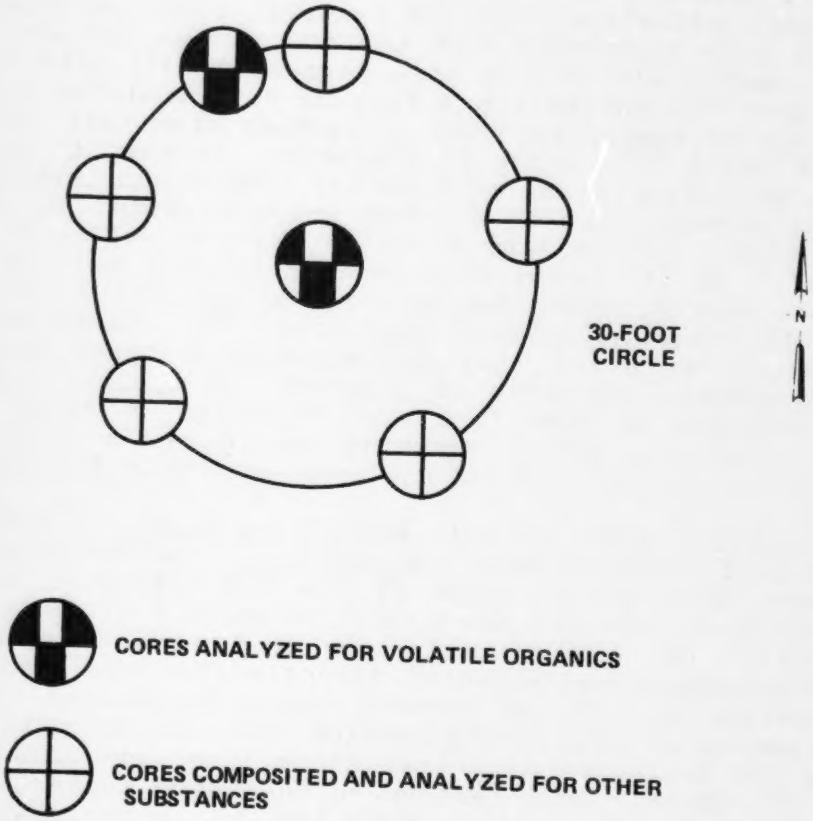

30-FOOT CIRCLE
N
CORES ANALYZED FOR VOLATILE ORGANICS
CORES COMPOSITED AND ANALYZED FOR OTHER SUBSTANCES

Figure 27. Typical Soil Sampling Configuration Used at Each Site.

TABLE 8. SIGNIFICANT DIFFERENCES OBSERVED IN EXTENT OF SOIL CONTAMINATION AT LOVE CANAL

Compound/Element	Percent Detect (Number of Samples) Decl.	Control	Canal	Comparison[†] Canal - Decl.	Decl. - Control
Phenanthrene	23.8 (105)	44.4 (9)	39.1 (23)	No (α=0.108)	No
α-BHC	8.3 (109)	0.0 (9)	26.1 (23)	Yes	No
δ-BHC	10.1 (109)	0.0 (9)	39.1 (23)	Yes	No
γ-BHC (Lindane)	6.4 (109)	0.0 (9)	21.7 (23)	Yes	No
Heptachlor epoxide	0.9 (109)	0.0 (9)	8.7 (23)	Yes	No
Endrin	9.2 (109)	0.0 (9)	26.1 (23)	Yes	No
DDT	5.5 (109)	0.0 (9)	21.7 (23)	Yes	No
1,1-Dichloroethene	2.3 (213)	0.0 (17)	17.8 (45)	Yes	No
Chloroform	19.2 (213)	41.2 (17)	42.2 (45)	Yes	No
3-Chlorotoluene	0.0 (213)	0.0 (17)	4.4 (45)	Yes	No
Chlorobenzene	1.4 (212)	0.0 (17)	6.7 (45)	Yes	No
Cadmium	4.6 (108)	0.0 (9)	39.1 (23)	Yes	No

[†] Comparisons are based on a one-tailed difference of proportions test (α=0.10), using Fisher's exact test, for the areas indicated, and in the order presented.

this finding was the observation that patterns of soil contamination detected in the Canal Area were often also in relatively close correspondence with the occurrence of shallow system ground-water contamination at Love Canal.

Even though direct evidence of Love Canal-related soil contamination was found in the Canal Area, relatively few statistically significant differences in the extent of soil contamination occur when the Canal Area is compared to control sites. This result was considered a likely consequence of: (1) the generally limited through-ground migration of substances from the former canal (recall that no soil samples were collected inside the boundary of the barrier drain system; (2) the preferential through-ground migration of substances from the former canal along relatively local, narrow, more-permeable soil pathways; (3) the selective overland flow of contaminants from the former canal that occurred prior to remedial construction (it was not possible to estimate the ameliorating effects of microbial degradation on either the extent or degree of soil contamination observed at Love Canal); and (4) the relatively small number of soil samples collected at control sites which limited the power of the statistical test employed. In addition, the relatively infrequent occurrence of quantifiable soil monitoring results also rendered a determination of differences in the degree of soil contamination found at Love Canal statistically impractical.

In Figures 28 through 31, four examples of soil monitoring findings are presented to illustrate the typical patterns of soil contamination found in the general Love Canal area (additional figures are included in Volume III). The substances displayed in these three figures are (respectively) benzene (from both of the two soil cores collected at each site for volatile organics), γ-BHC, and cadmium. As before, the maximum concentration of the substance of interest observed at each site is presented. From the results displayed in these figures it can be seen that soil contamination, which was directly attributable to contaminants having migrated from Love Canal, was confined to the Canal Area. Furthermore, no consistent patterns of contamination migrating out of the Canal Area were found in the soil monitoring data.

Additional detailed analyses of the soil monitoring data revealed that soil contamination which was directly attributable to the migration of contaminants from Love Canal was confined to the Canal Area. In particular, substantial Canal Area soil contamination was prevalent at site 11018 (741 97th Street), which was the soil sampling site located closest to the known sand lens on the 97th Street side of Love Canal, and at site 11005 (684 99th Street), which was located in the former major swale that crossed Love Canal. Both of these sites are located in ring 1.

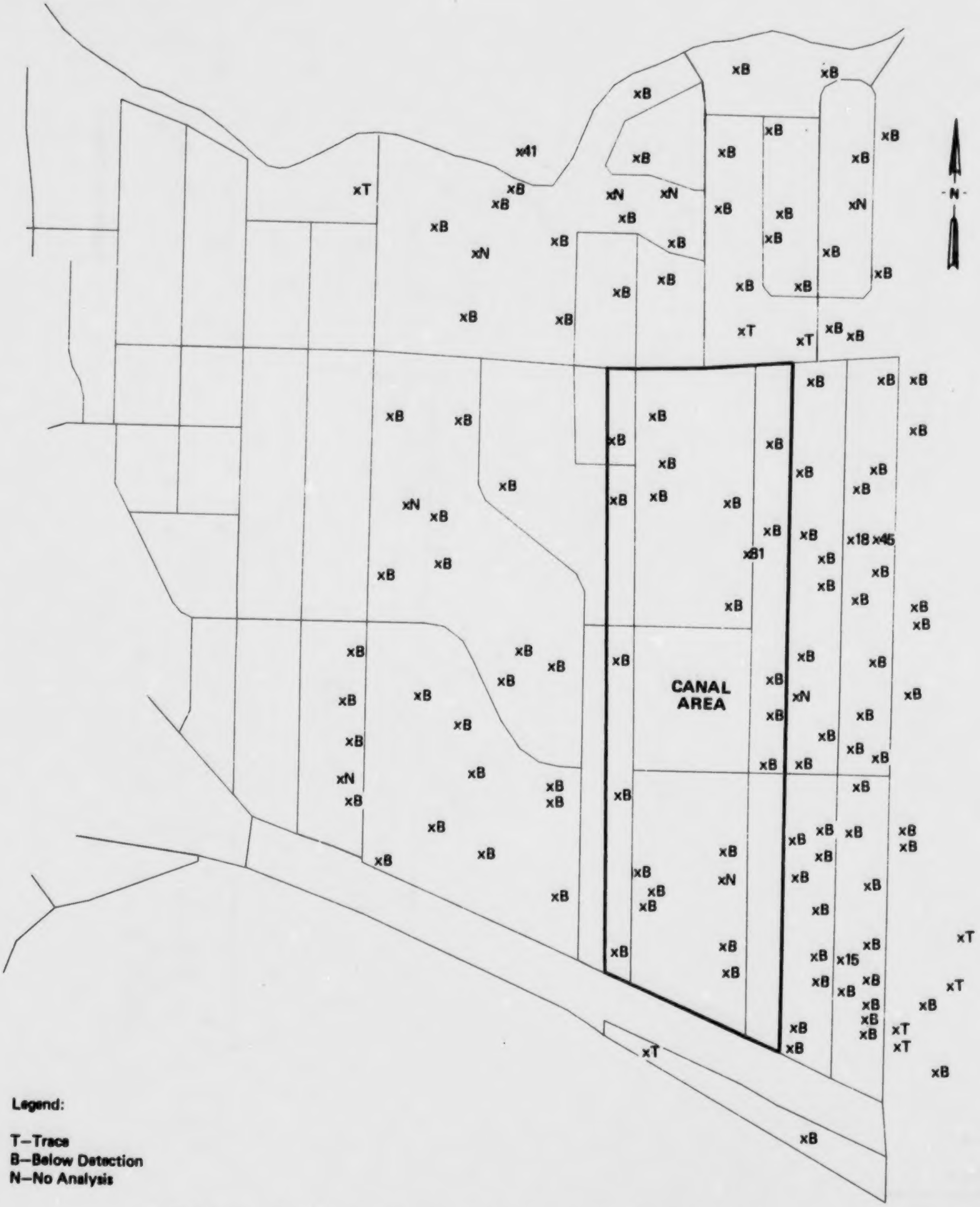

N
CANAL AREA
x41
x81
x18
x45
x15
xT
xN
xB
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 28. Soil Sampling Sites (First), Benzene, Maximum Concentrations (micrograms per kilogram, ppb).

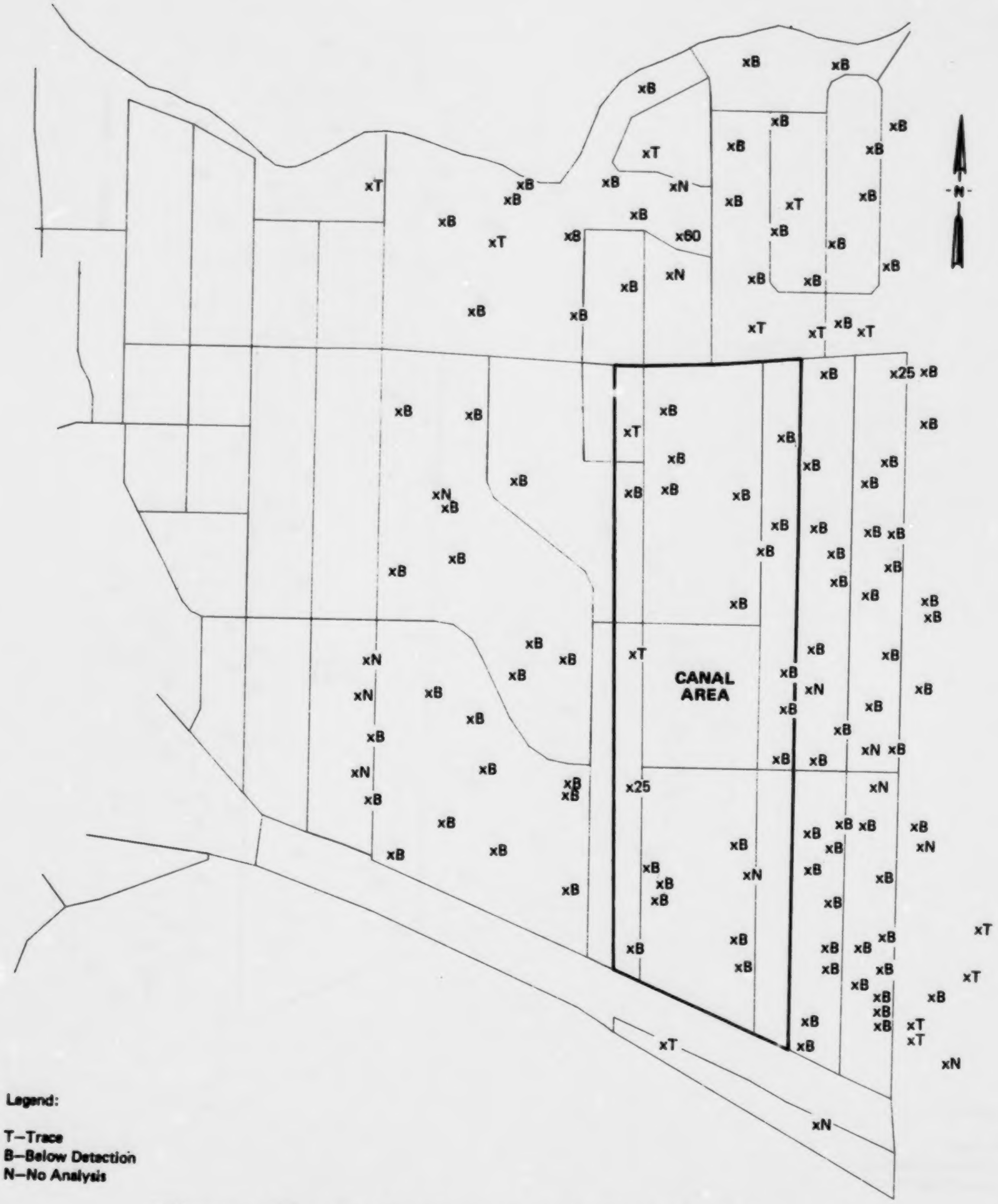

N
CANAL AREA
xB
xT
xN
x60
x25
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 29. Soil Sampling Sites (Second), Benzene, Maximum Concentrations (micrograms per kilogram, ppb).

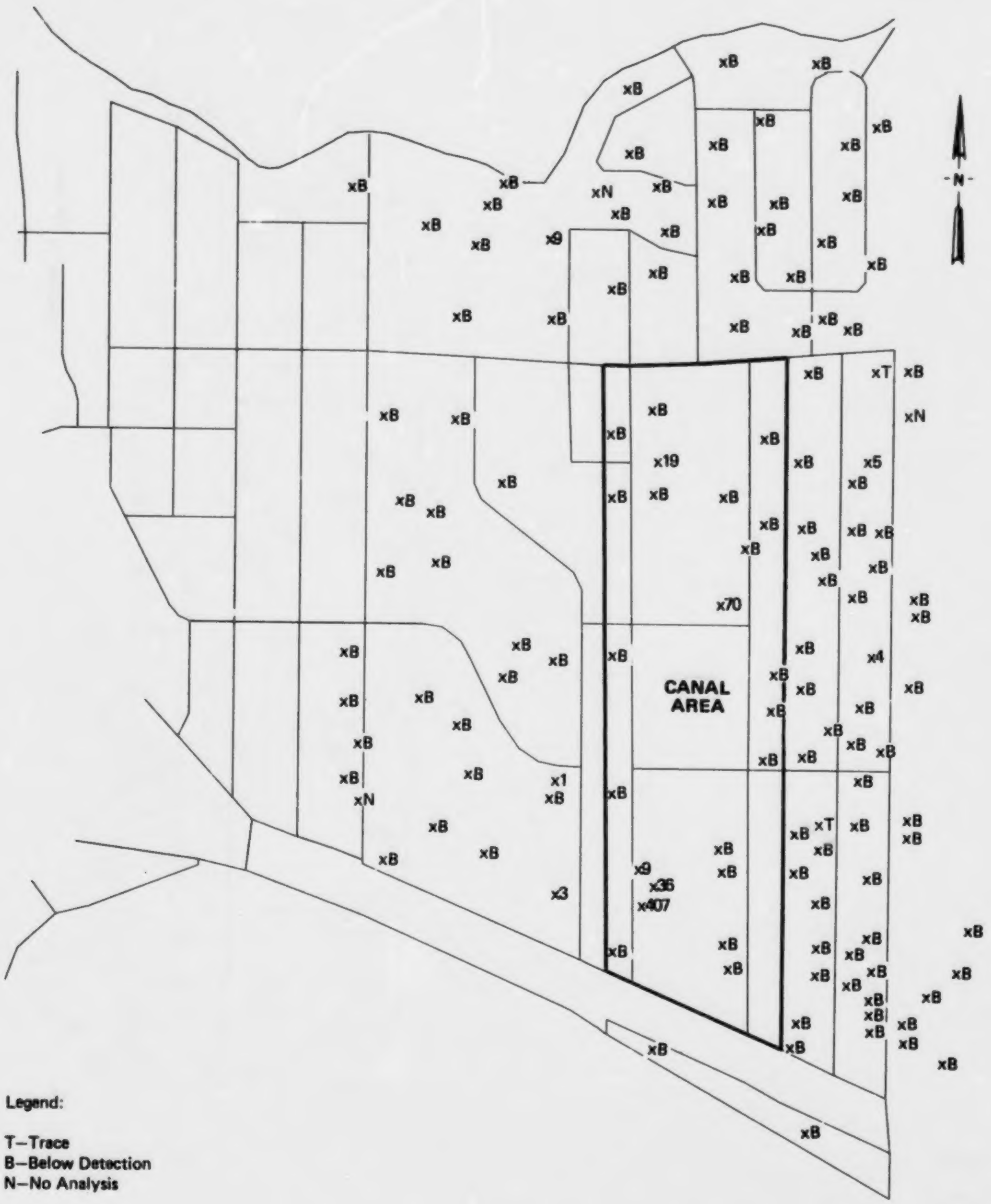

-N-
CANAL AREA
x19
x70
x5
x4
xT
x1
x9
x36
x407
x3
xB
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 30. Soil Sampling Sites,
γ-BHC, Maximum Concentrations
(micrograms per kilogram, ppb).

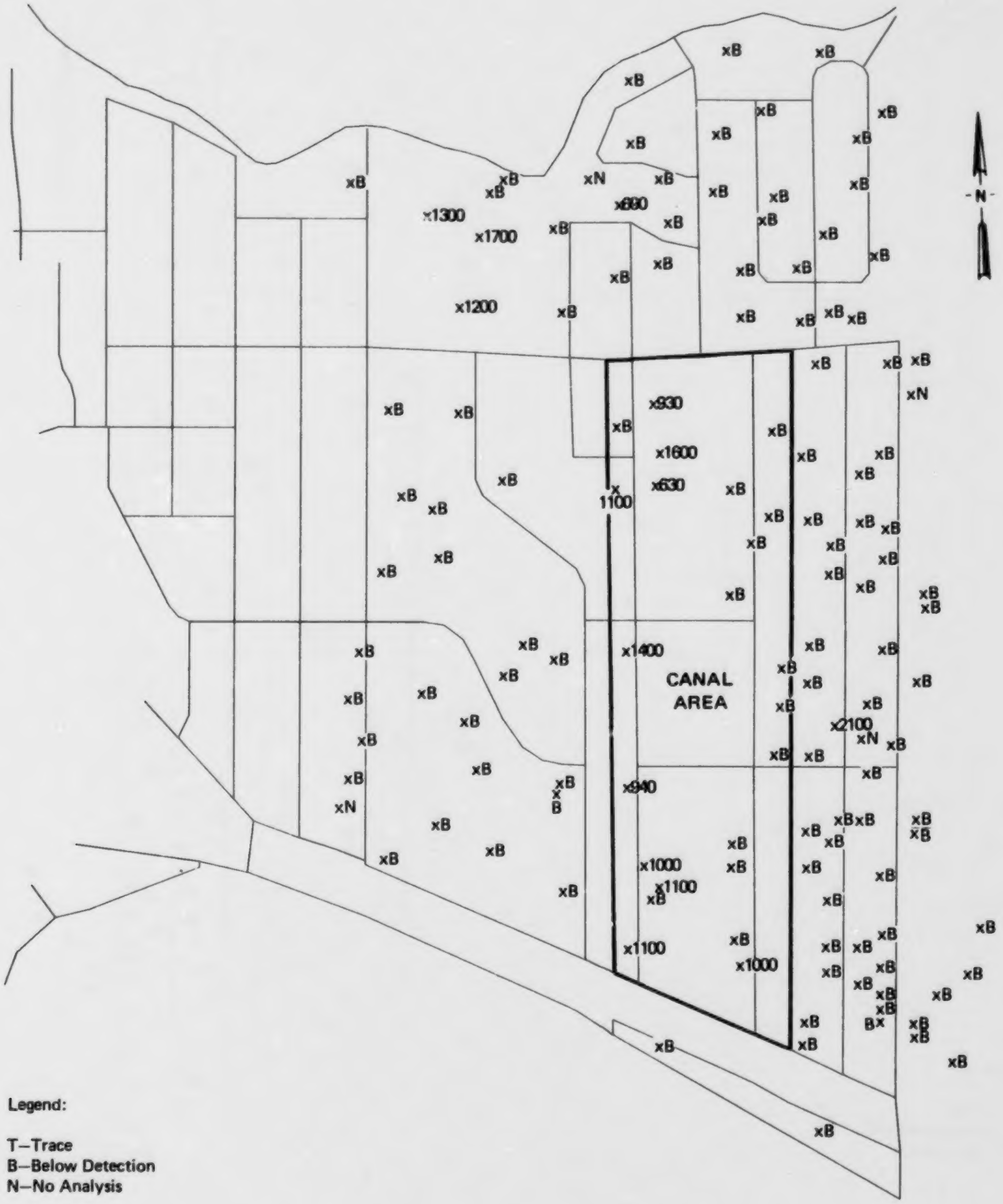

N
xB
xN
x1300
x1700
x1200
x660
x930
x1600
x630
x 1100
x1400
CANAL AREA
x2100
x940
x1000
x1100
x1100
x1000
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 31. Soil Sampling Sites, Cadmium, Maximum Concentrations (micrograms per kilogram ppb).

Even though relatively prevalent soil contamination was also observed at a few other sites, the absence of compelling evidence revealing a gradient of soil contamination emanating from Love Canal towards those sites, suggested that the observed contamination was not due to the natural migration of contaminants from the landfill. Rather, it is likely that soil contamination found in the Declaration Area occurred from other causes because no pattern of soil contamination was found outside of the Canal Area that corresponded to the shallow system ground-water gradient, and only isolated instances of soil contamination were found in the Declaration Area (and these were often at substantial distances from the former canal). A total of 10 soil sampling sites (out of the 171 sampled) had organic contaminants present at only trace or lower concentration levels.

4.2.3 Sump Contamination

The objective of the sump monitoring program was to provide, through indirect means, additional evidence of Love Canal-related environmental contamination involving shallow system ground water and soil. Such indirect evidence would be obtained whenever Love Canal-related contamination was found present in sump water samples. In order to attribute sump contamination to the migration of contaminants from Love Canal, the monitoring program was designed to assist in demonstrating that contamination migrating from Love Canal had been taken-up from the ground water by basement sumps, and was not present due to other causes. Furthermore, it was recognized that contaminated basement sumps could also serve as sources of potential human exposure to toxic substances that might pose a threat to human health. Because human exposure to contaminants taken-up by basement sumps could also occur by inhalation of volatilized airborne pollutants, a special program of sump/basement-air monitoring was designed and conducted at Love Canal.

The sump was stirred to obtain a sample of the entire sump contents, because the amount of sediment present in sumps was not ordinarily adequate for sampling purposes (except for a few Canal Area residences). These sump water samples were collected routinely and analyzed for the targeted substances identified in Appendix A. At two Canal Area residences (site 11072 at 771 97th Street, and site 11071 at 779 97th Street), sufficient amounts of sediment were present in the sumps and both sump water and sump sediment samples were collected and analyzed for targeted substances. At each of the base residences, sump water samples were collected at the same time, and with approximately the same frequency, as the regular air monitoring campaigns were conducted. In other sites at which sumps were sampled only one routine collection of sump water samples was performed.

An initial undisturbed sample of water was collected at all sump sampling sites for the determination of targeted volatile organic compounds. Subsequent to the collection of this sample, the sump was vigorously agitated with a paddle for 2 minutes to simulate the turbulence caused by the activation of a sump pump. Additional samples of sump water were then collected for the analysis of other targeted substances.

The extent and degree of sump water contamination at Love Canal was determined through the collection and analysis of sump water samples from 54 sites (Figure 32). As with other environmental media sampled at Love Canal, sump sampling sites were selected to satisfy a number of different criteria: (1) sites were often intentionally selected (when in existence and available for sampling) along suspected preferential soil transport pathways; (2) sumps were sampled in residences where the occupants reported the suspected presence of contaminants; (3) sumps were repetitively sampled in each base residence for the purpose of multimedia monitoring; and (4) sumps were randomly (with equal probability) selected for sampling from throughout the entire Declaration Area. In addition to the samples collected at multimedia monitoring sites, nine sites in the Canal Area were sampled as part of the previously mentioned special sump/basement-air study. Due to program constraints and limited voluntary access to residences outside of the Declaration Area, only one control site sump (located in a residence on Grand Island) was sampled.

The results from the sump monitoring program revealed a pattern of environmental contamination consistent with the findings of the hydrogeologic program, and corresponding to both the ground-water and soil monitoring findings. The pattern of sump contamination observed revealed that substantial amounts of contaminants had preferentially migrated directly from Love Canal prior to remedial construction and been taken-up by sumps located in certain ring 1 residences. In particular, evidence of residual sump water contamination (and in two instances, evidence of high residual sump sediment contamination), that was directly attributable to the migration of contaminants from Love Canal, was found in: (1) those ring 1 residences that were suspected of having been subjected historically to the overland flow of contaminants from the landfill prior to remedial construction; and (2) those ring 1 residences that had been constructed in the vicinity of more permeable soil pathways conveying through-ground migration of contaminants from Love Canal prior to remedial construction. Due to a lack of appropriate historical data, it was not possible to determine the amount of the residual contamination observed in these ring 1 sump samples that had been degraded through natural processes. It is important to note that the sump pumps in all Canal Area residences which were sampled had been disconnected and inoperable since 1979, at least 1 year prior to EPA monitoring. A summary of the statistically significant sump water monitoring findings is presented in Table 9. Once again, note that the Type I error rate is larger than α.

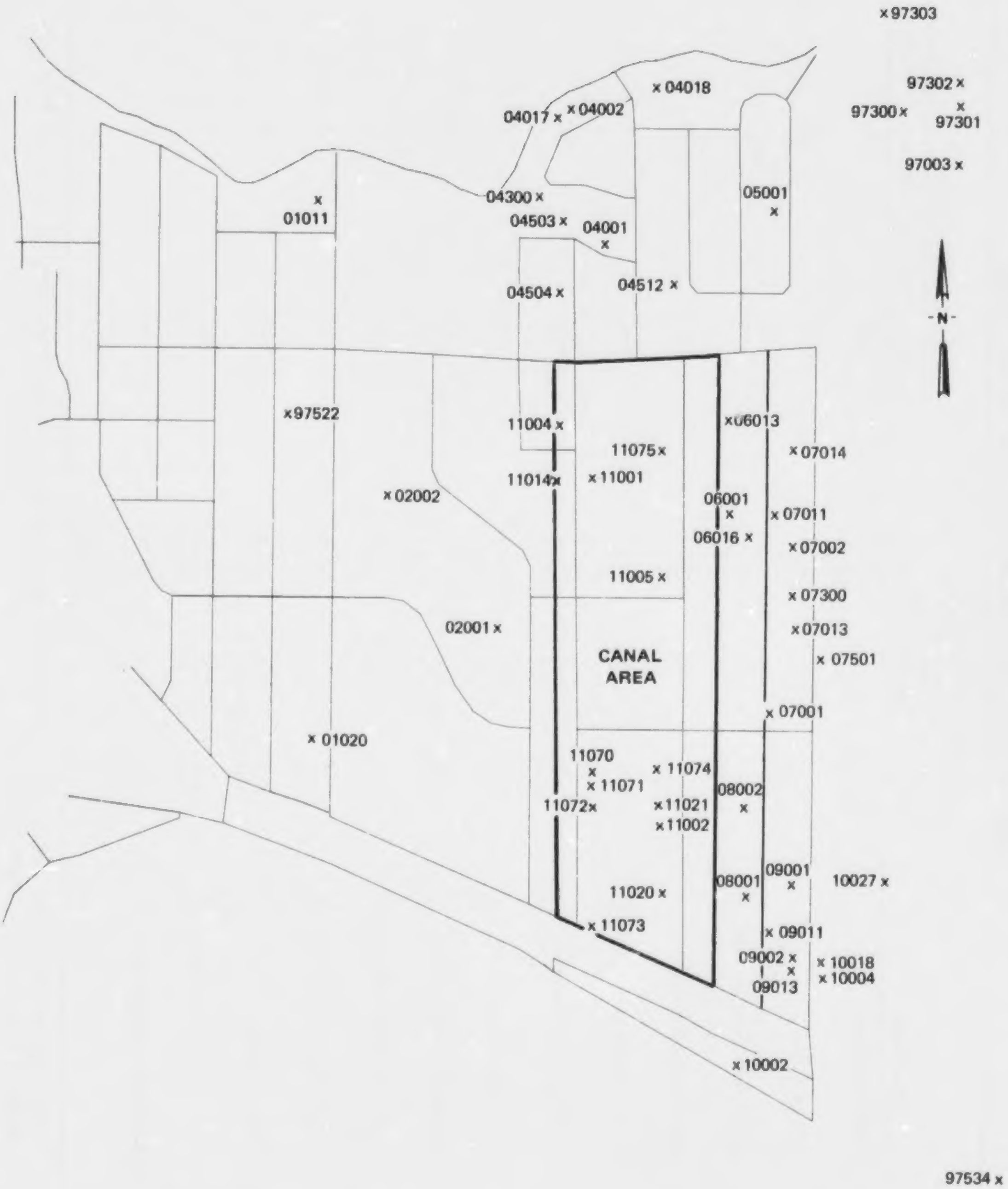

97303
97302
97300
97301
97003
04018
04017
04002
04300
04503
04001
05001
01011
04504
04512
N
97522
11004
06013
11075
07014
11014
11001
02002
06001
07011
06016
07002
11005
07300
02001
07013
CANAL AREA
07501
07001
01020
11070
11074
11071
08002
11072
11021
11002
09001
10027
08001
11020
09011
11073
09002
10018
10004
09013
10002
97534

Figure 32. Sump Water Sampling Site Codes.

TABLE 9. SIGNIFICANT DIFFERENCES OBSERVED IN THE EXTENT OF SUMP WATER CONTAMINATION AT LOVE CANAL

Compound	Percent Detect (Number of Samples)			Comparison†	
	Decl.	Control	Canal	Canal - Decl.	Decl. - Control
2-Nitrophenol	0.0 (104)	0.0 (4)	23.1 (13)	Yes	No
Phenol	4.8 (104)	0.0 (4)	30.8 (13)	Yes	No
4-Chloro-3-methylphenol	0.0 (104)	0.0 (4)	15.4 (13)	Yes	No
Hexachloroethane	0.0 (103)	0.0 (4)	23.1 (13)	Yes	No
1,4-Dichlorobenzene	11.5 (104)	0.0 (4)	46.2 (13)	Yes	No
1,3-Dichlorobenzene	1.9 (104)	0.0 (4)	53.8 (13)	Yes	No
1,2-Dichlorobenzene	0.0 (104)	0.0 (4)	38.5 (13)	Yes	No
Hexachlorobutadiene	0.0 (104)	0.0 (4)	30.8 (13)	Yes	No
1,2,3-Trichlorobenzene	0.0 (104)	0.0 (4)	15.4 (13)	Yes	No
1,2,4-Trichlorobenzene	0.0 (104)	0.0 (4)	53.8 (13)	Yes	No
Naphthalene	6.7 (104)	0.0 (4)	30.8 (13)	Yes	No
2,4-Dichlorotoluene	0.0 (104)	0.0 (4)	23.1 (13)	Yes	No
Hexachlorobenzene	1.0 (104)	0.0 (4)	38.5 (13)	Yes	No

(continued)

---

† Comparisons were based on a one-tailed difference of proportions test ($\alpha=0.10$), using Fisher's exact test, for the areas indicated, and in the order presented.

TABLE 9 (continued)

Compound	Percent Detect (Number of Samples)			Comparison†	
	Decl.	Control	Canal	Canal - Decl.	Decl. - Control
Anthracene	10.6 (104)	0.0 (4)	38.5 (13)	Yes	No
1,2,3,4-Tetrachlcrobenzene	0.0 (104)	0.0 (4)	46.2 (13)	Yes	No
Tetrachlorotoluenes	0.0 (89)	0.0 (4)	36.4 (11)	Yes	No
α-BHC	17.1 (105)	40.0 (5)	42.9 (14)	Yes	No
β-BHC	17.1 (105)	0.0 (5)	35.7 (14)	No (α =0.102)	No
δ-BHC	14.4 (104)	20.0 (5)	35.7 (14)	Yes	No
γ-BHC (Lindane)	18.1 (105)	20.0 (5)	50.0 (14)	Yes	No
trans-1,2-Dichloroethene	0.0 (104)	0.0 (5)	31.3 (14)	Yes	No
Chloroform	7.7 (104)	0.0 (5)	37.5 (16)	Yes	No
1,2-Dichloroethane	1.0 (104)	0.0 (5)	12.5 (16)	Yes	No
Trichloroethene	1.9 (104)	0.0 (5)	31.3 (16)	Yes	No
Benzene	7.7 (104)	40.0 (5)	43.8 (16)	Yes	No
1,1,2,2-Tetrachloroethane	0.0 (104)	0.0 (5)	18.8 (16)	Yes	No

(continued)

---

†Comparisons were based on a one-tailed difference of proportions test (α=0.10), using Fisher's exact test, for the areas indicated, and in the order presented.

TABLE 9 (continued)

Compound	Percent Detect (Number of Samples)			Comparison[†]	
	Decl.	Control	Canal	Canal - Decl.	Decl. - Control
o-Xylene	1.9 (104)	0.0 (5)	25.0 (16)	Yes	No
m-Xylene	3.8 (104)	0.0 (5)	31.3 (16)	Yes	No
Tetrachloroethene	14.4 (104)	0.0 (5)	37.5 (16)	Yes	No
Toluene	16.3 (104)	20.0 (5)	43.8 (16)	Yes	No
2-Chlorotoluene	0.0 (90)	0.0 (5)	40.0 (15)	Yes	No
3-Chlorotoluene	0.0 (90)	0.0 (5)	40.0 (15)	Yes	No
Chlorobenzene	1.9 (104)	0.0 (5)	37.5 (16)	Yes	No
Ethyl benzene	3.9 (90)	0.0 (5)	25.0 (16)	Yes	No

[†] Comparisons were based on a one-tailed difference of proportions test ($\alpha=0.10$), using Fisher's exact test, for the areas indicated, and in the order presented.

As can be seen from the results presented in Table 9, and from a review of the tables included in Volume III, the sump water monitoring data revealed that direct Love Canal-related environmental contamination (note, for example, the chlorinated benzenes and chlorinated toluenes) was confined to the Canal Area. Supporting these statistical findings was the observation that patterns of sump water contamination found in the Canal Area were also ordinarily closely associated with the occurrence of both shallow system ground-water contamination and soil contamination.

Three examples of typical sump water monitoring results are presented in Figures 33 through 35 to illustrate the pattern of sump water contamination found at Love Canal (additional figures are included in Volume III). The compounds displayed in these figures are benzene, toluene, and γ-BHC (Lindane), respectively. As was done previously, the maximum concentration of the compound of interest observed at each site is presented. In Figures 33 through 35 it can be seen that the pattern of sump water contamination revealed by the data is consistent with the findings of shallow system ground-water contamination displayed in Figures 20 through 22, and the findings of soil contamination displayed in Figures 28 through 31. In particular, note that (once again) evidence of direct Love Canal-related environmental contamination is restricted to the vicinity of certain ring 1 residences in the Canal Area.

Additional detailed analyses of the sump monitoring data revealed that sump water contamination directly attributable to the migration of contaminants from Love Canal was confined to the Canal Area. In particular, Canal Area contamination was prevalent at the following sites, all located in ring 1: site 11071 at 779 97th Street; site 11070 at 783 97th Street; site 11072 at 771 97th Street; site 11021 at 476 99th Street; site 11073 at 703 97th Street; and site 11005 at 684 99th Street. It is noteworthy that the three most highly contaminated sumps (identified by the sump water monitoring data) were located: (1) in those ring 1 residences closest in proximity to the known sand lens located on the western side of Love Canal, south of Wheatfield Avenue; (2) near the highly contaminated shallow system well number 77A, which was installed through the known sand lens in ring 1 at 775 97th Street; and (3) near the highly contaminated ring 1 soil sampling site 11012 at 741 97th Street, which was the soil sampling site located closest to the sand lens. In addition, evidence of both sump water contamination and soil contamination were identified at site 11005 (684 99th Street), which was previously noted as being located along the former major swale that crossed Love Canal. (See Figures 2 and 14). Of the 54 sites sampled for sump water contamination, a total of 11 sites had organic contaminants present at only trace or lower concentration levels.

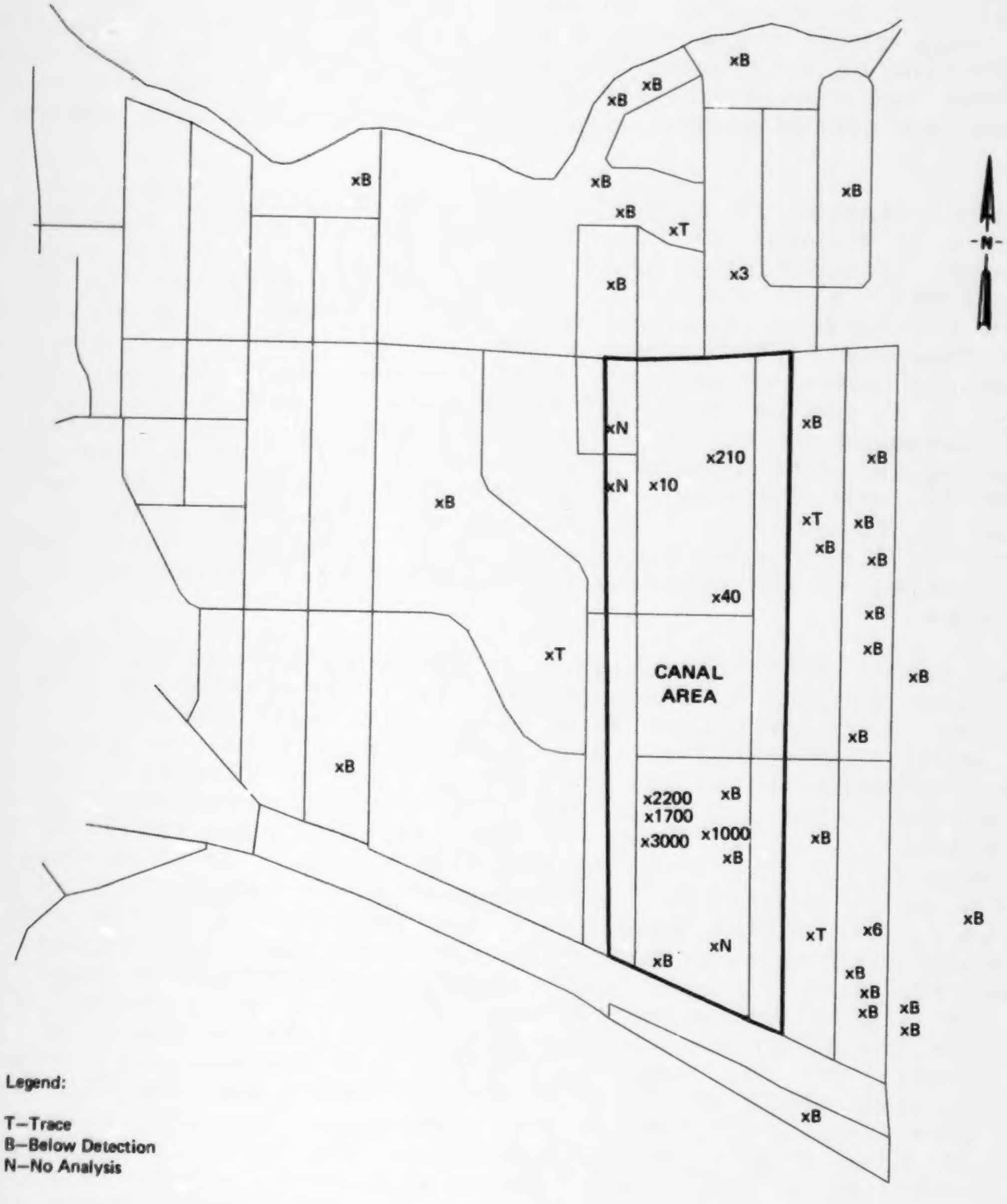

xB
xB
xB
xB
xB
xB
xB
xT
xB
x3
-N-
xN
x210
xB
xN
x10
xB
xB
xT
xB
xB
xB
x40
xB
xB
xT
CANAL AREA
xB
xB
xB
x2200
x1700
x3000
xB
x1000
xB
xB
xT
x6
xB
xN
xB
xB
xB
xB
xB
xB
xB
xB
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 33. Sump Water Sampling Sites, Benzene, Maximum Concentrations (micrograms per liter, ppb).

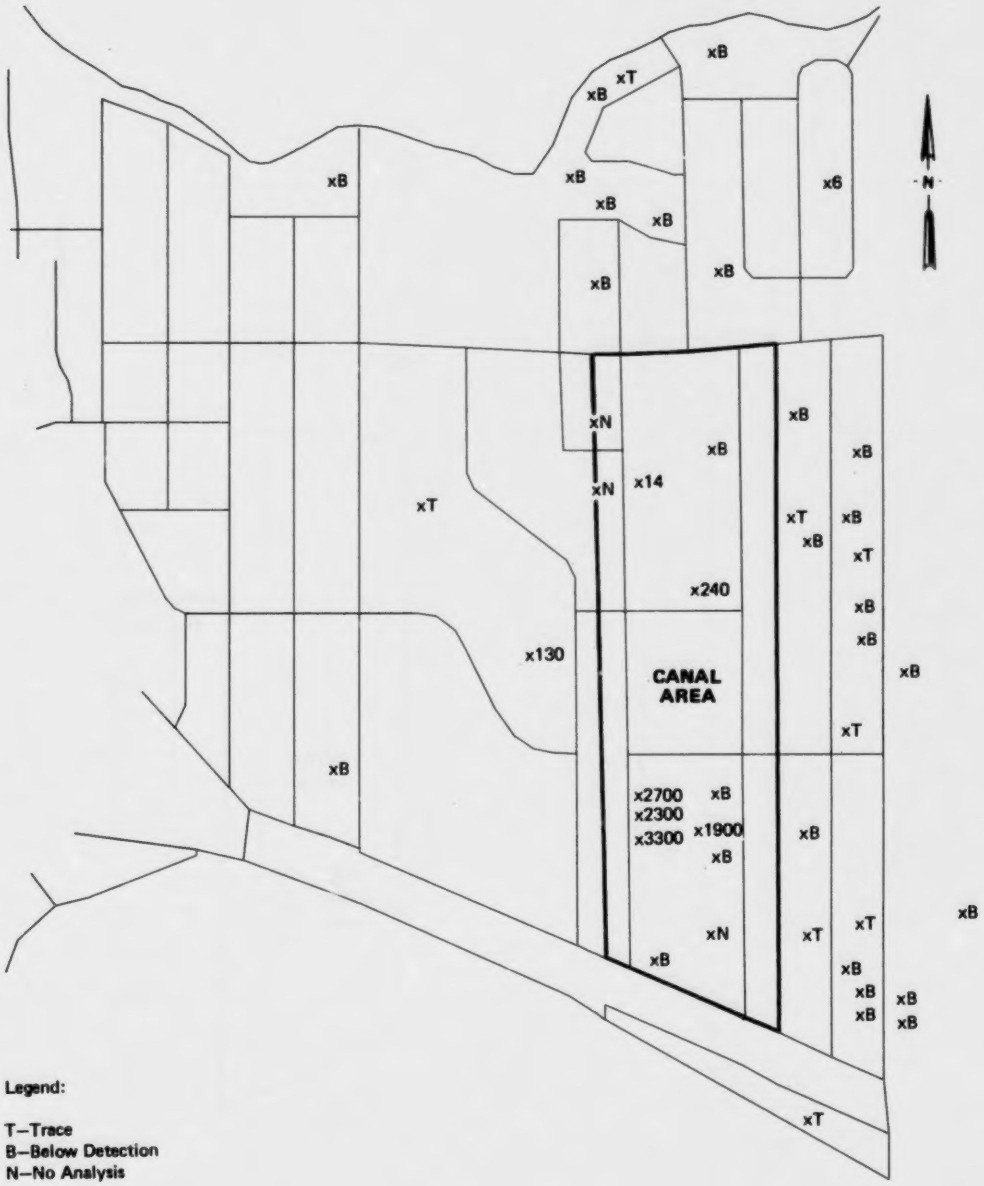

xB
xT
xB
xB
xB
xB
xB
x6
N
xB
xB
xN
xB
xB
xB
x14
xN
xT
xT
xB
xB
xT
x240
xB
xB
x130
CANAL AREA
xB
xT
xB
x2700
x2300
x3300
xB
x1900
xB
xB
xB
xN
xT
xT
xB
xB
xB
xB
xB
xB
xB
xT
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 34. Sump Water Sampling Sites, Toluene, Maximum Concentrations (micrograms per liter, ppb).

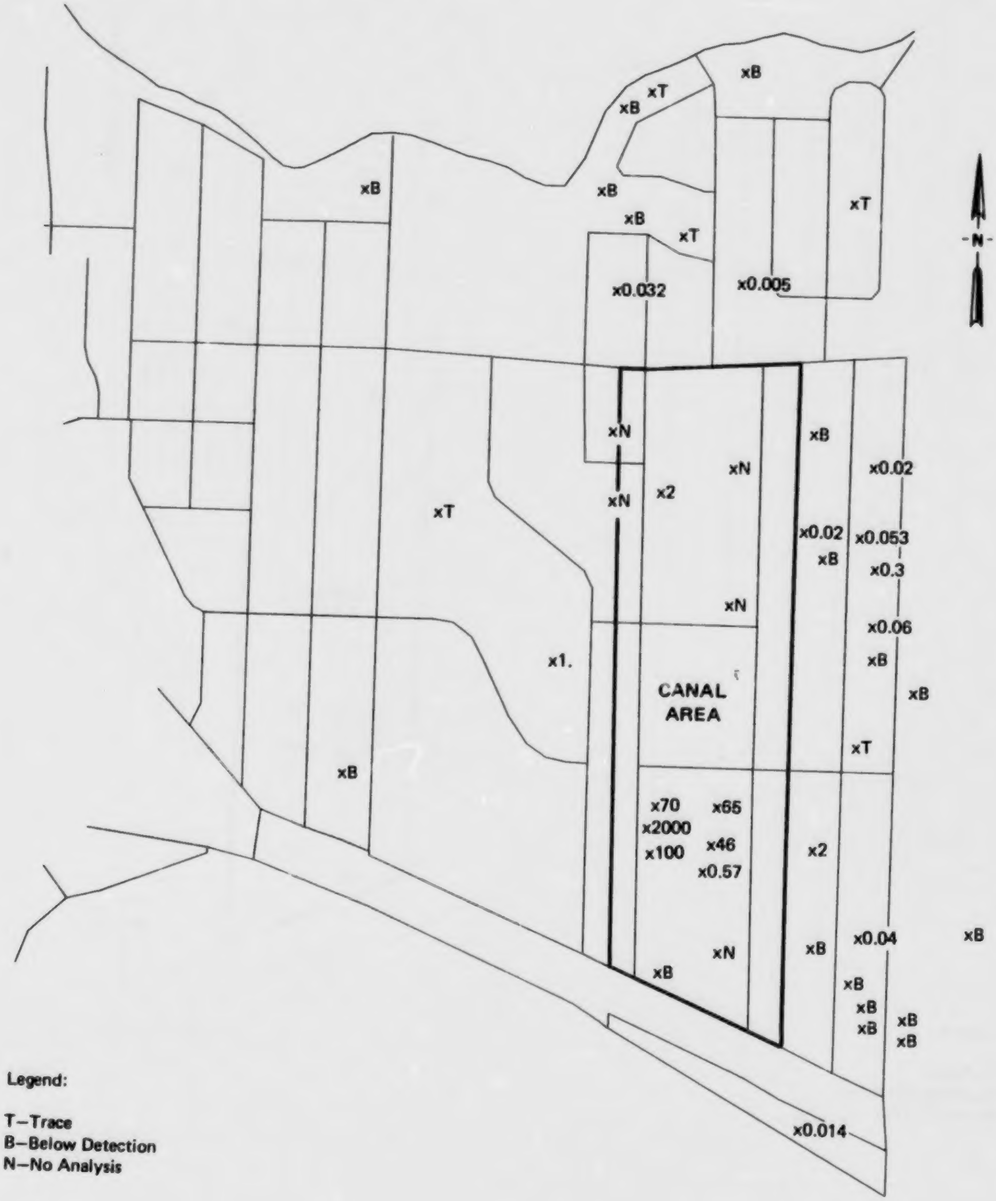

xB
xB
xT
xB
xB
xT
xB
xT
x0.032
x0.005
N
xN
xB
xN
x0.02
xN
x2
xT
x0.02
x0.053
xB
x0.3
xN
x0.06
x1.
xB
CANAL AREA
xB
xT
xB
x70
x65
x2000
x46
x100
x0.57
x2
x0.04
xB
xN
xB
xB
xB
xB
xB
xB
xB
x0.014
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 35. Sump Water Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per liter, ppb).

Because only two sump sites were found to have sufficient sediment present for sampling and analysis purposes, an extensive discussion of the monitoring results obtained is unnecessary. The reason for this is because it is sufficient to note that at sump sampling sites 11071 (779 97th Street) and 11072 (771 97th Street), where both sump water and sump sediment samples were collected, high contamination of both media was present.

Now, it is well known that many of the organic compounds monitored at Love Canal are both hydrophobic and readily sorbed on sediments. That is, their equilibrium sorption behavior, as characterized by the partition coefficient K_p or K_{oc}, is relatively high; see, for example, S. W. Karickhoff, "Semi-Empirical Estimation of Sorption of Hydrophobic Pollutants on Natural Sediments and Soils," Chemosphere, Vol. 10 (1981), 833-846. Therefore, it was not surprising to find the presence of highly contaminated (solution phase) sump water in association with the presence of very high concentrations (sorbed phase) of certain organic contaminants present in the sump sediment (particularly since the sump water had not been refreshed by pumping, and consequently diluted, since 1979). The reader interested in the specific results obtained from the analysis of sump sediment samples is referred to Volume II.

Before concluding this section it is perhaps worth mentioning again that, prior to remedial construction in 1979, Canal Area basement sumps were discharged into the local storm sewer lines on 97th and 99th Streets. The likely consequences of this activity on the distant transport of contaminants from Love Canal into the surrounding environment are discussed in the next two sections of the report.

4.2.4 Sanitary and Storm Sewer Contamination

Samples of sanitary sewer water and sediment were collected from the Love Canal Declaration Area access point located at the intersection of Wheatfield Avenue and 101st Street (site 08016, see Volume II). This particular sampling location was selected because it was directly connected to the portion of the sanitary sewer line that was installed across the landfill, under Wheatfield Avenue, by the City of Niagara Falls in 1957. In addition, the location selected was sufficiently far from Love Canal to (potentially) provide evidence of the distant transport of infiltrated contaminants. Because the sanitary sewer line under Wheatfield Avenue was encompassed by the barrier drain system in 1979 and plugged at 99th Street by the city in early 1980, it was deemed likely that any residual contamination present in the line would be due to historical transport.

From the analysis performed on the sanitary sewer samples collected, the presence of Love Canal-related contaminants in both sanitary sewer water and sanitary sewer sediment samples was revealed clearly, with higher concentration levels present in the sediment samples. In particular, a number of substances detected in the sanitary sewer samples were identified as indicators of the direct migration of contaminants from Love Canal (the specific results may be found in Volume II). For example, in sanitary sewer water samples a number of chlorinated toluenes were found; while in sanitary sewer sediment samples, evidence of high contamination was found involving chlorinated benzenes, chlorinated toluenes, and hexachlorocyclopentadiene (C-56).

A total of 29 sampling sites (identified where possible in Figure 36) were included in the storm sewer portion of the monitoring program. Storm sewer sampling was conducted during the months of August and October 1980, and involved the collection and analysis of water and sediment samples (when available in adequate amounts) for the targeted substances identified in Appendix A. In a previous section (4.1.1.2) on topography and drainage, the existence, location, and direction of water-flow in storm sewer lines in the immediate vicinity of Love Canal was discussed; they were graphically displayed in Figure 12.

Also discussed in Section 4.1.1.2 was the existence and location of certain features that, prior to remedial construction, may have contributed to the transport of contaminants from Love Canal into the nearby storm sewers. These included: (1) a French drain around the 99th Street Elementary School that was connected to a storm sewer line on 99th Street; (2) storm sewer laterals on Read and Wheatfield Avenues that were connected to storm sewer lines on 97th and 99th Streets; and (3) a catch basin at 949-953 97th Street located near the boundary of the former canal that was connected to a storm sewer line on 97th Street. In addition, it was noted that prior to remedial construction, the overland flow of surfaced contaminants may have reached the encircling streets where they would have been captured by the existing curb drains.

From that which was discussed previously in Sections 4.2.1 and 4.2.2 it may be concluded that prior to remedial construction at Love Canal, a potential existed for the migration (through permeable soil pathways) of contaminants from the former canal into the storm sewer lines on 97th and 99th Streets, and laterals on Read and Wheatfield Avenues. As a result of remedial measures taken at the site, however, it is likely that only residual contamination remains in the affected storm sewer lines. From the information presented in Section 4.2.3, it must also be concluded that, prior to 1979, the sumps of certain ring 1 residences served to collect, and subsequently discharge, contaminants into the storm sewer lines with which they were connected. Based on the monitoring evidence presented in Section 4.2.3, it is likely that the storm sewer line on 97th Street, south of Wheatfield Avenue, received the greatest amount of contamination through this mechanism. Furthermore, it is highly unlikely (based on the

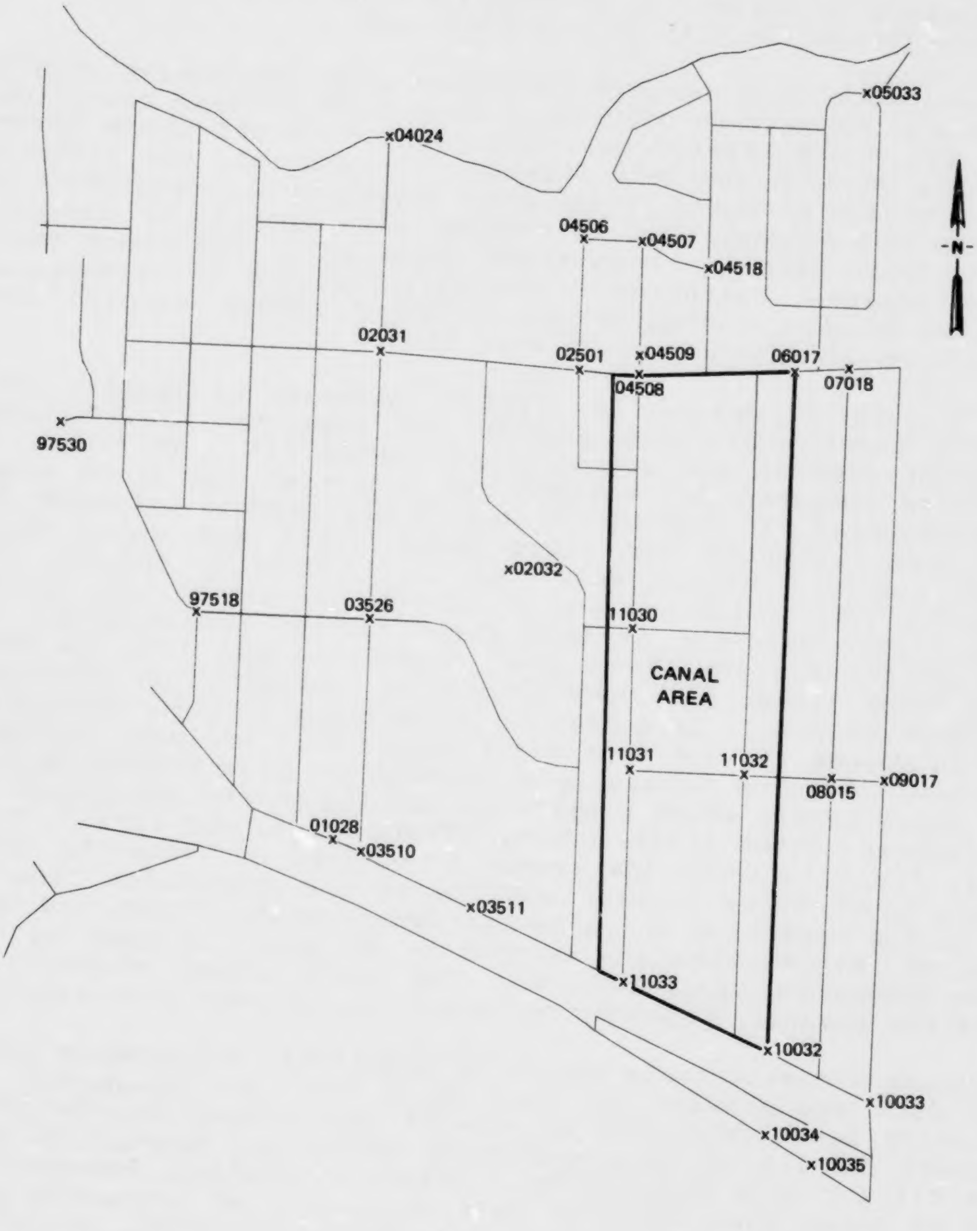

x04024
x05033
04506
x04507
x04518
-N-
02031
02501
x04509
06017
04508
07018
97530
x02032
97518
03526
11030
CANAL AREA
11031
11032
08015
x09017
01028
x03510
x03511
x11033
x10032
x10033
x10034
x10035

Figure 36. Storm Sewer Sampling Site Codes.

evidence presented in Sections 4.2.1 through 4.2.3) that storm sewers sampled in the Declaration Area would display evidence of direct Love Canal-related contamination, except for those storm sewers that directly connect to the storm sewer lines originating on 97th and 99th Streets. Because all storm sewers in the general Love Canal area that connect to Canal Area storm sewer lines were displayed in Figure 12, no additional details on storm sewer water-flow directions will be presented here.

The evidence obtained from the storm sewer monitoring program revealed a clear pattern of direct, Love Canal-related contamination in all storm sewer lines that connect to the storm sewers originating on 97th and 99th Streets. In general, the patterns of contamination revealed by the data suggested the occurrence of decreasing contaminants concentrations with increasing distance from the Canal Area, in both storm sewer water and storm sewer sediment samples. Furthermore, the data revealed no evidence of Love Canal-related contamination in storm sewers sampled that were isolated from direct Canal Area flow.

In Figures 37 through 41, typical examples of results from the storm sewer monitoring program are presented. Additional storm sewer figures are presented in Volume III. In Figure 37 the results obtained for benzene are presented for storm sewer sediment samples; in Figures 38 and 39 the results obtained for toluene are presented for storm sewer water and storm sewer sediment samples, respectively; and in Figures 40 and 41, the results for γ-BHC (Lindane) are presented. As can be seen in the figures, clear evidence of Love Canal-related contamination is evident in those storm sewers that connect to the 97th and 99th Streets sewer lines, with high levels of contamination displayed in sediment samples. In addition, it is clear from the data presented in Volume II, and from the figures, that sediment contamination concentration levels were related to accumulation points in the storm sewers which consist of turning points and junctions (for examples, sites 11033, 04508, 02501, 04506, and 11031). Presumably, the relatively low levels of organic contaminants found in storm sewer water samples was due to the continuing flow of water in the operating storm sewers (which would dilute the concentration levels), the low solubility in water of some of the organic compounds monitored, and the preferential sorption of some of the organic compounds monitored on sediment particles.

Because a considerable amount of additional storm sewer monitoring data are similar to that which was just presented, no other storm sewer data will be offered. The reader interested in additional details of this monitoring effort may consult Volumes II and III for more information. Before concluding, however, it should be noted that numerous Love Canal-related compounds were found in both storm sewer water and sediment samples, including chlorinated benzenes and toluenes, and a number of pesticides such as the four targeted isomers of hexachlorocyclohexane (BHC).

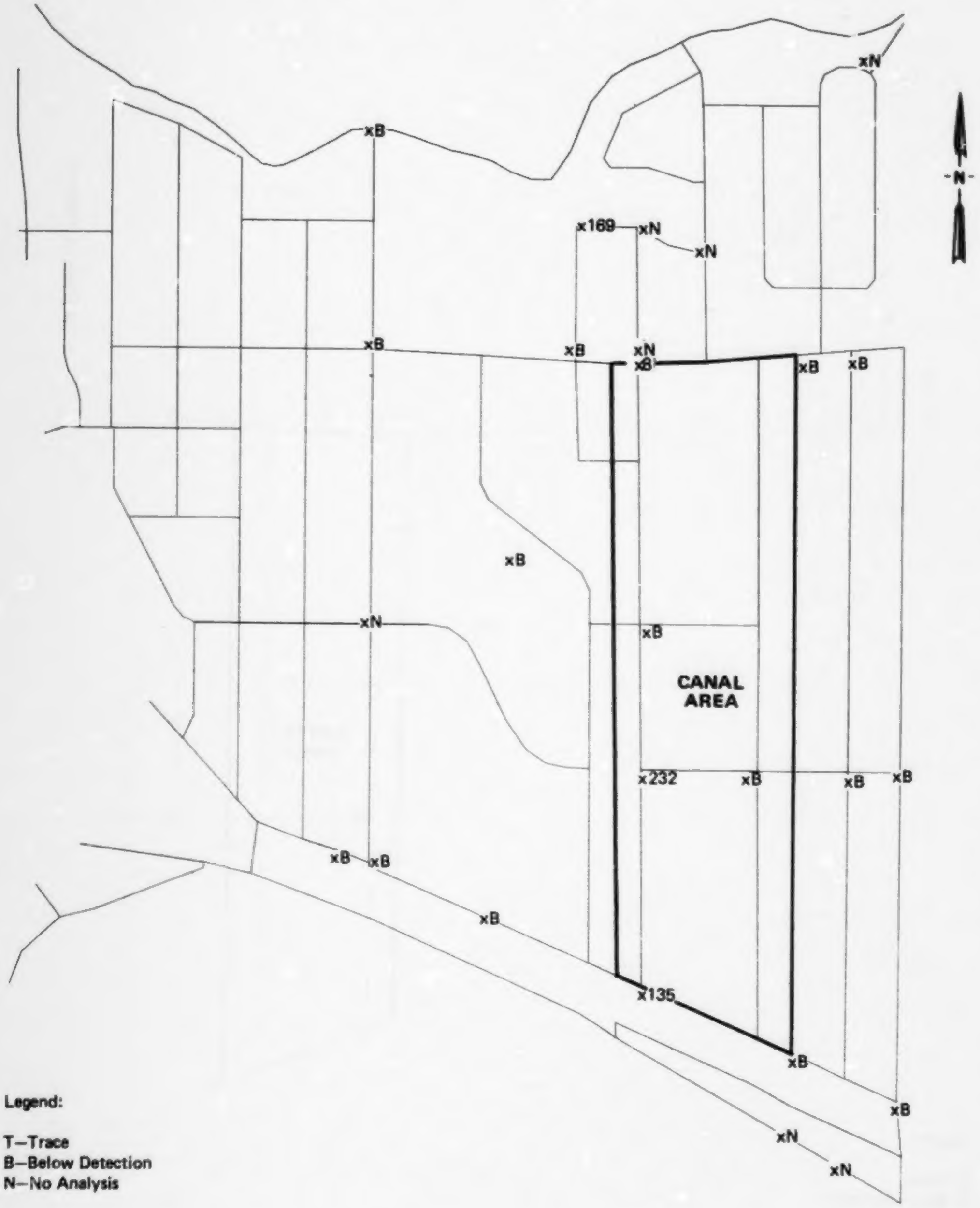
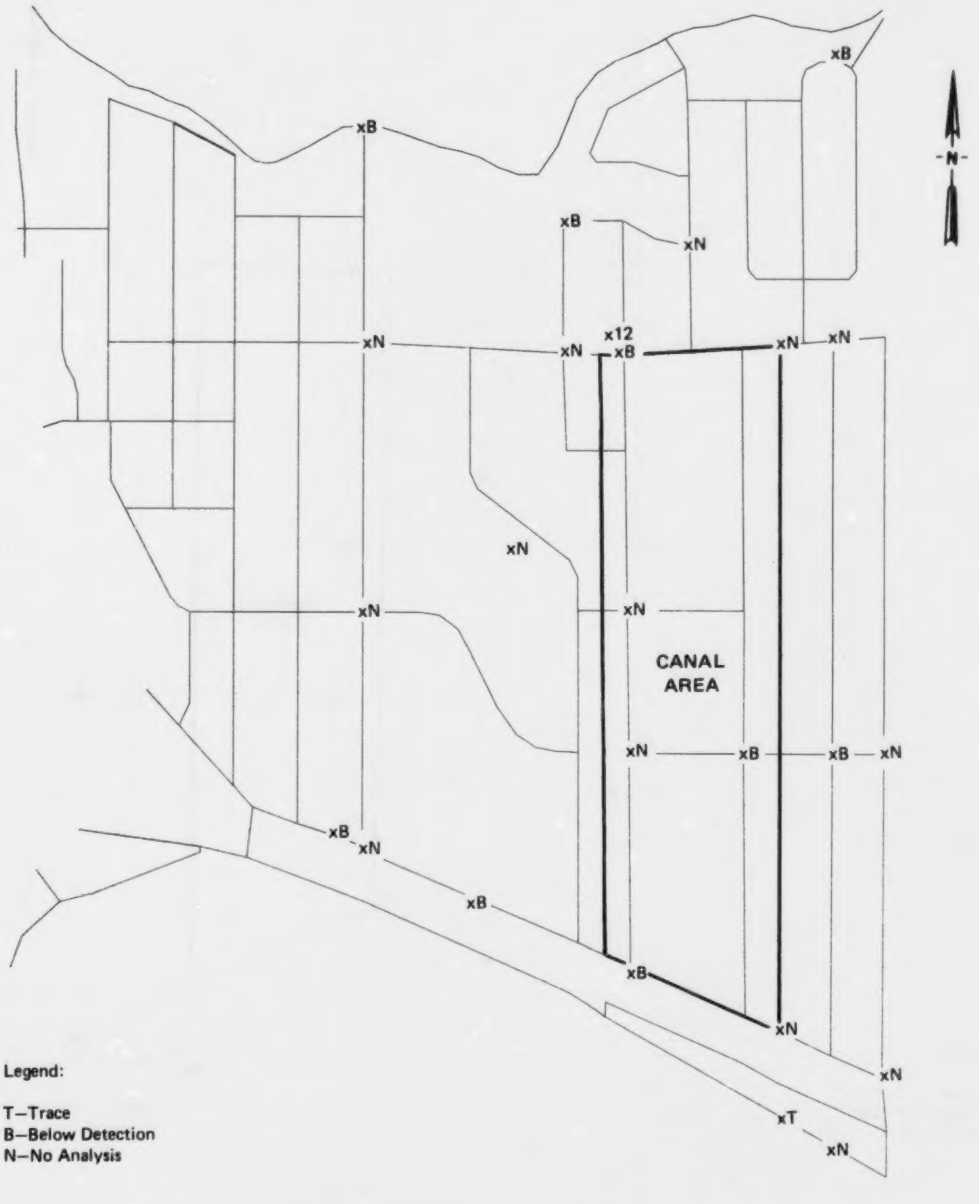

xN
xB
-N-
x169
xN
xN
xB
xB
xN
xB
xB
xB
xB
xN
xB
CANAL AREA
x232
xB
xB
xB
xB
xB
xB
x135
xB
xB
xN
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 37. Storm Sewer Sediment Sampling Sites, Benzene, Maximum Concentrations (micrograms per kilogram, ppb).



xB
xB
-N-
xB
xN
xN
x12
xN
xB
xN
xN
xN
xN
xN
xN
CANAL
AREA
xN
xB
xB
xN
xB
xN
xB
xB
xN
xN
xT
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 38. Storm Sewer Water Sampling Sites,
Toluene, Maximum Concentrations
(micrograms per liter, ppb).

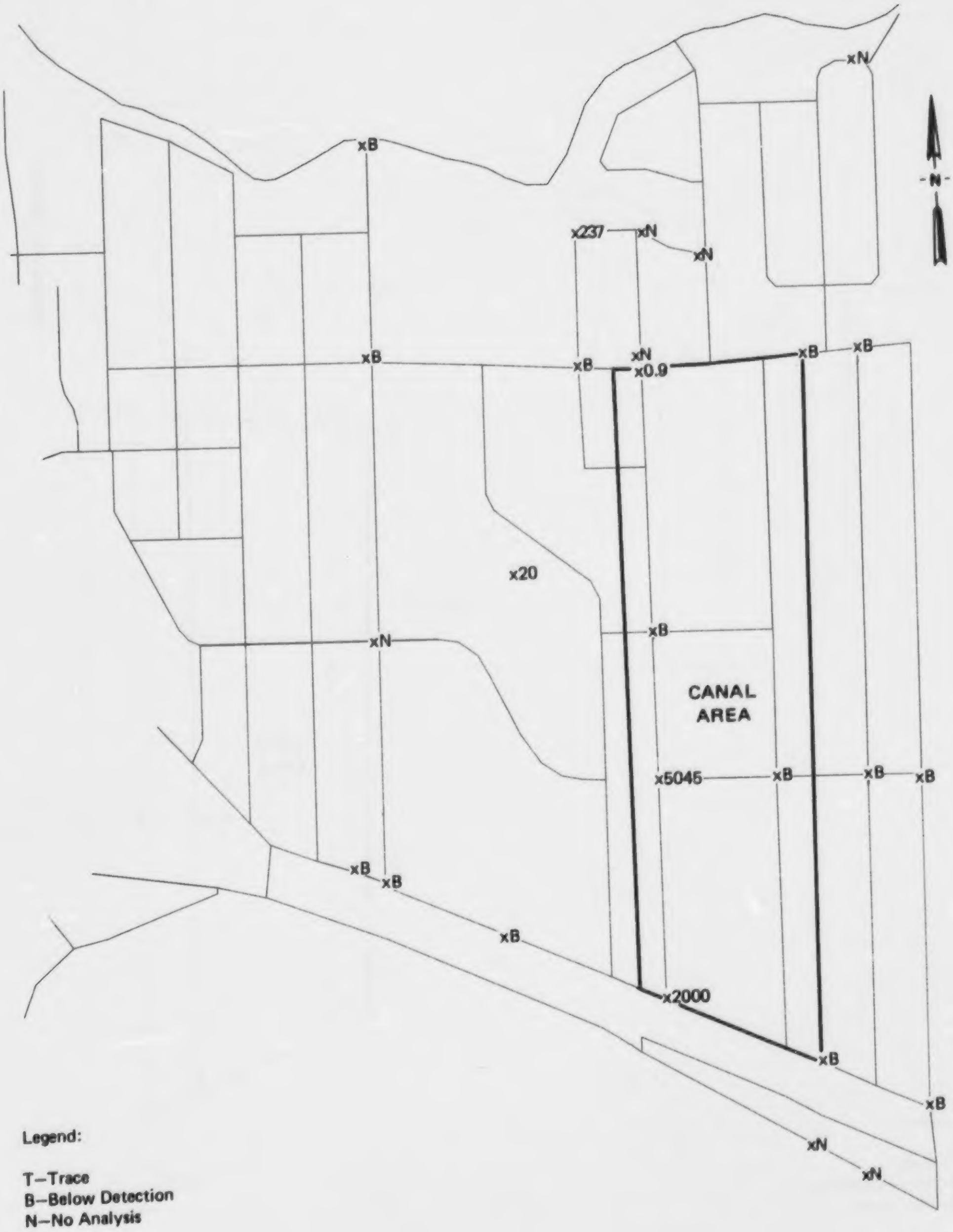

xN
xB
N
x237
xN
xN
xB
xB
xN
x0.9
xB
xB
x20
xB
CANAL
AREA
xN
x5045
xB
xB
xB
xB
xB
xB
x2000
xB
xB
xN
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 39. Storm Sewer Sediment Sampling Sites, Toluene, Maximum Concentrations (micrograms per kilogram, ppb).

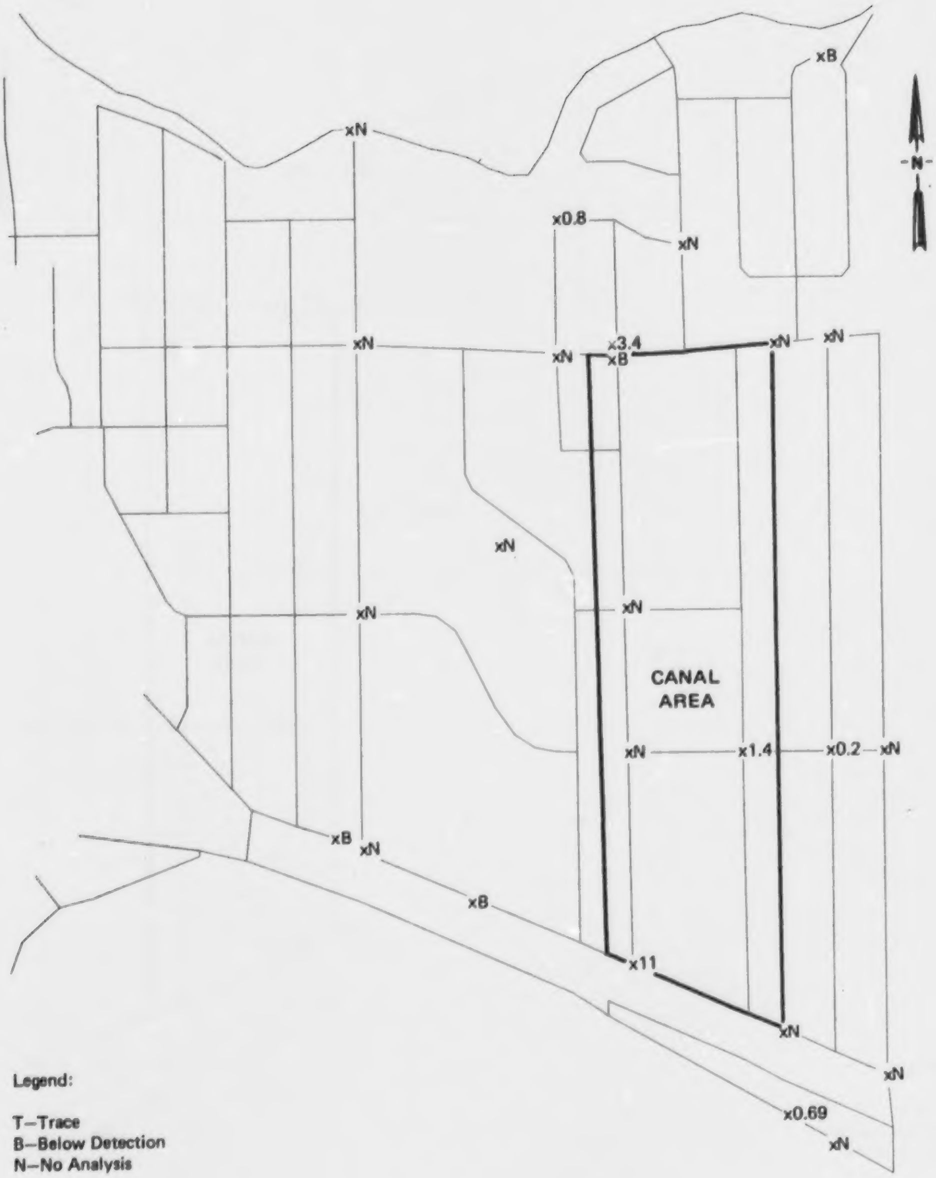

xB
N
xN
x0.8
xN
xN
x3.4
xN
xB
xN
xN
xN
xN
xN
CANAL AREA
xN
x1.4
x0.2
xN
xB
xN
xB
x11
xN
xN
x0.69
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 40. Storm Sewer Water Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per liter, ppb).

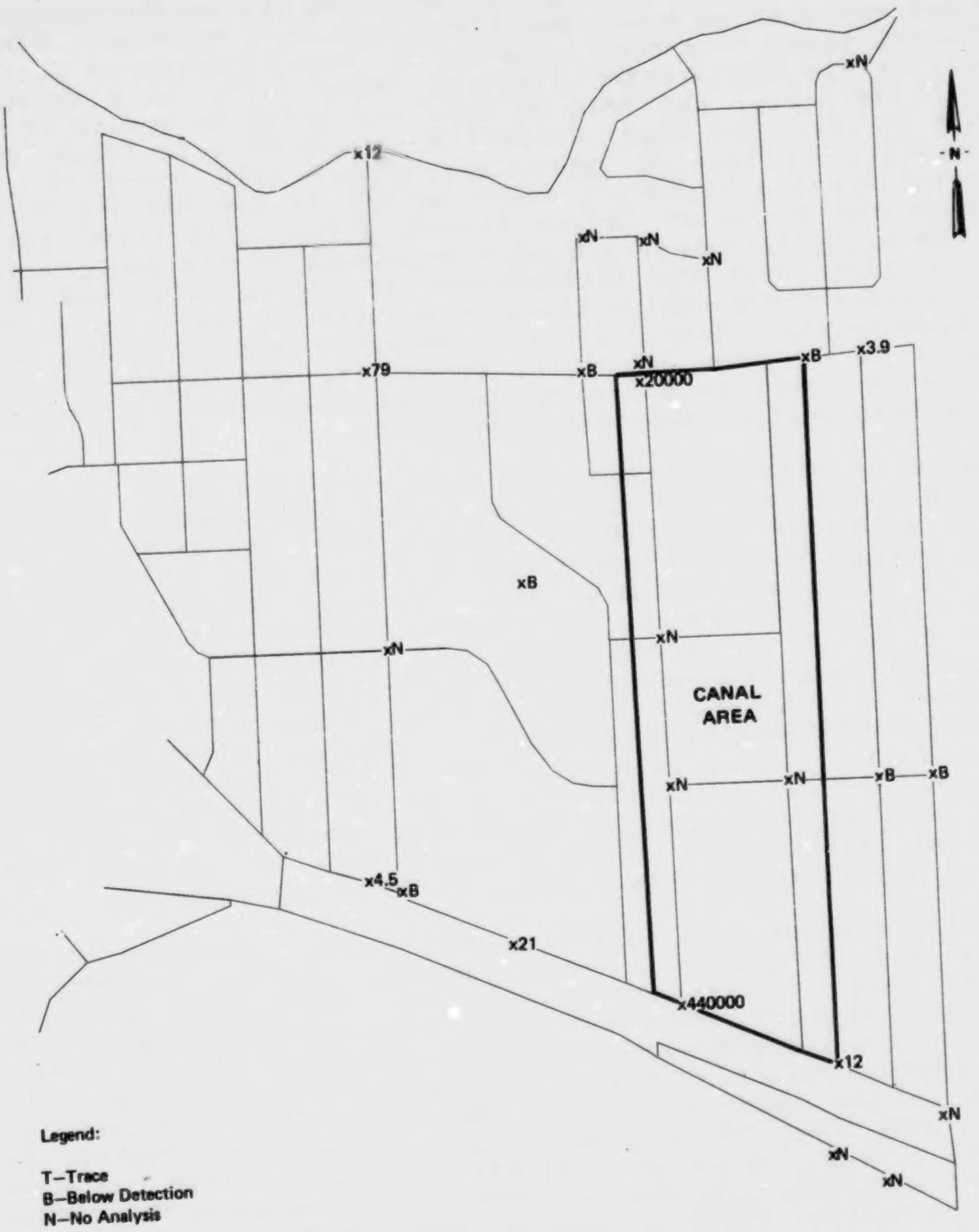

N
xN
x12
xN
xN
xN
x79
xB
xN
x20000
xB
x3.9
xB
xN
CANAL AREA
xN
xN
xB
xB
x4.5
xB
x21
x440000
x12
xN
xN
xN
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 41. Storm Sewer Sediment Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per kilogram, ppb).

4.2.5 Surface Water and Stream Sediment Contamination

Surface waters in the general Love Canal area are identified in Figures 1 and 3, and were discussed briefly in Section 4.1.1.2. To reiterate, Bergholtz Creek forms the northern boundary of the Declaration Area, and flows from east to west. Black Creek, which flows from east to west, is located north of Colvin Boulevard in the Declaration Area, is below grade in a culvert between 102nd Street and 98th Street, and joins Bergholtz Creek near 96th Street. The upper Niagara River, which also flows from east to west, is located approximately 1/4 mile south of the Declaration Area; a tributary known as the Little Niagara River circles to the north of Cayuga Island. Bergholtz Creek joins Cayuga Creek approximately 1/4 mile northwest of the Declaration Area at a point near the intersection of Cayuga Drive and 88th Street. Cayuga Creek, which flows from north to south, joins the Little Niagara River near South 87th Street. Because of the gentle slopes to the beds in Black, Bergholtz, and Cayuga Creeks, water-flow is known to occasionally experience gentle reversals due to certain weather-dependent conditions.

Samples of water and sediment were collected from 19 sites located in the creeks and rivers mentioned previously. The location of each site selected for surface water and sediment sampling is presented, where possible, in Figure 42. In addition, samples of water and sediment were collected from Fish Creek, north of Niagara University, for control purposes. As can be seen from the location of surface water and sediment sampling sites presented in Figure 42, and from the location of storm sewer outfalls shown in Figure 12, sites in Black Creek and the Niagara River were intentionally selected in relatively close proximity to the outfalls. Sites in Black Creek, Bergholtz Creek, the Niagara River, and the Little Niagara River were also sampled downstream from Love Canal-related storm sewer outfalls, in order to obtain some idea of the likely distance that contaminants from Love Canal may have been transported in those waterways.

Sediment samples were collected in a manner analogous to the procedure used for collecting soil samples. Namely, a number of subsamples were collected at a site and homogenized prior to analysis for targeted substances other than volatile organic compounds. Separate sediment samples were collected for the analysis of targeted volatile organic compounds. A sampling pattern, dependent on the space available, similar to that displayed in Figure 27 was used for the collection of sediment samples in creeks and rivers. Wherever possible, an Ekman dredge was used to collect sediment samples; at times, a stainless steel trowel was used to collect sediment samples when the depth and hardness of accumulated sediments prohibited use of the dredge.

In Figures 43 through 47, typical examples of the results obtained from the surface water and stream sediment monitoring

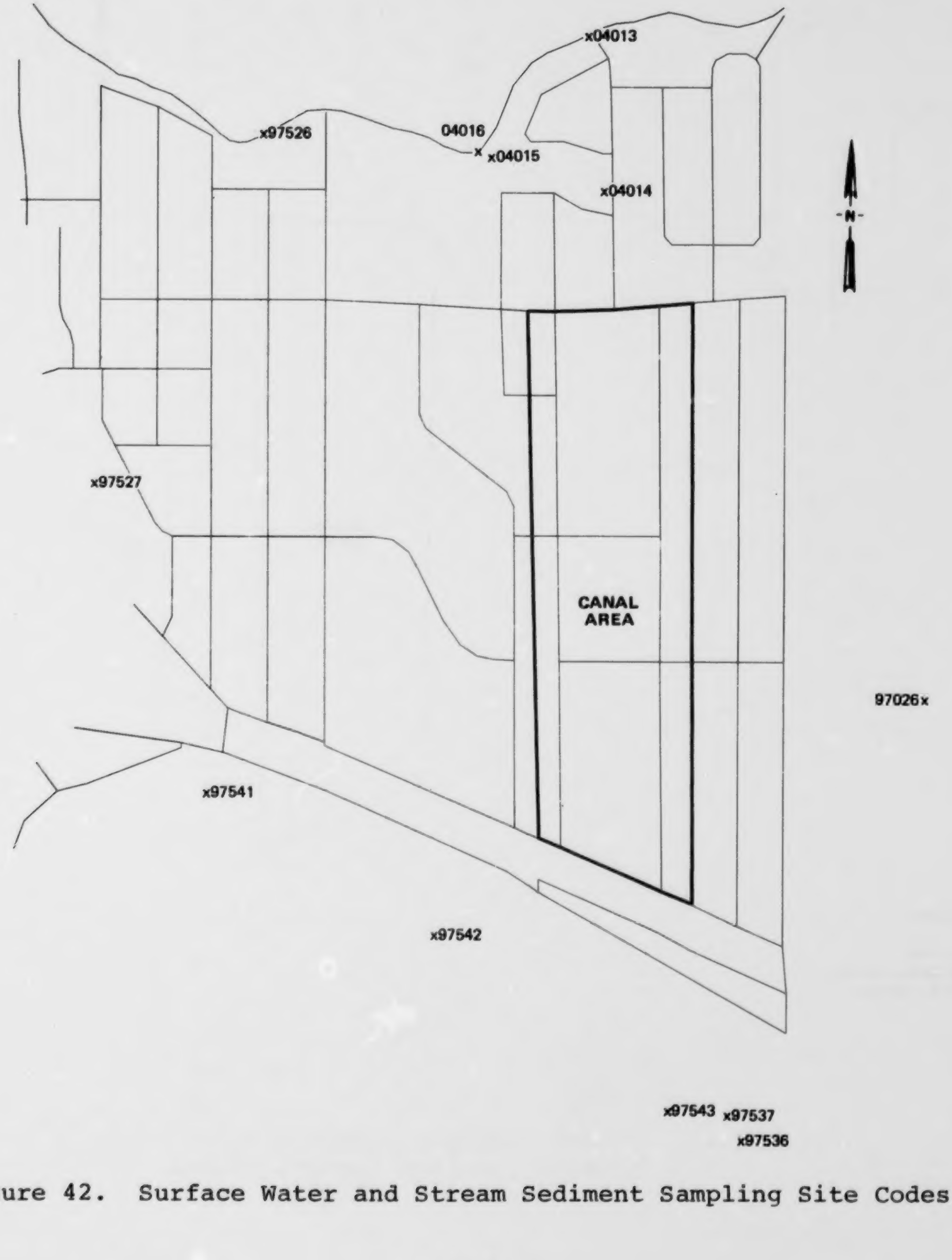

x04013
x97526
04016
x04015
x04014
N
x97527
CANAL AREA
97026x
x97541
x97542
x97543
x97537
x97536

Figure 42. Surface Water and Stream Sediment Sampling Site Codes.

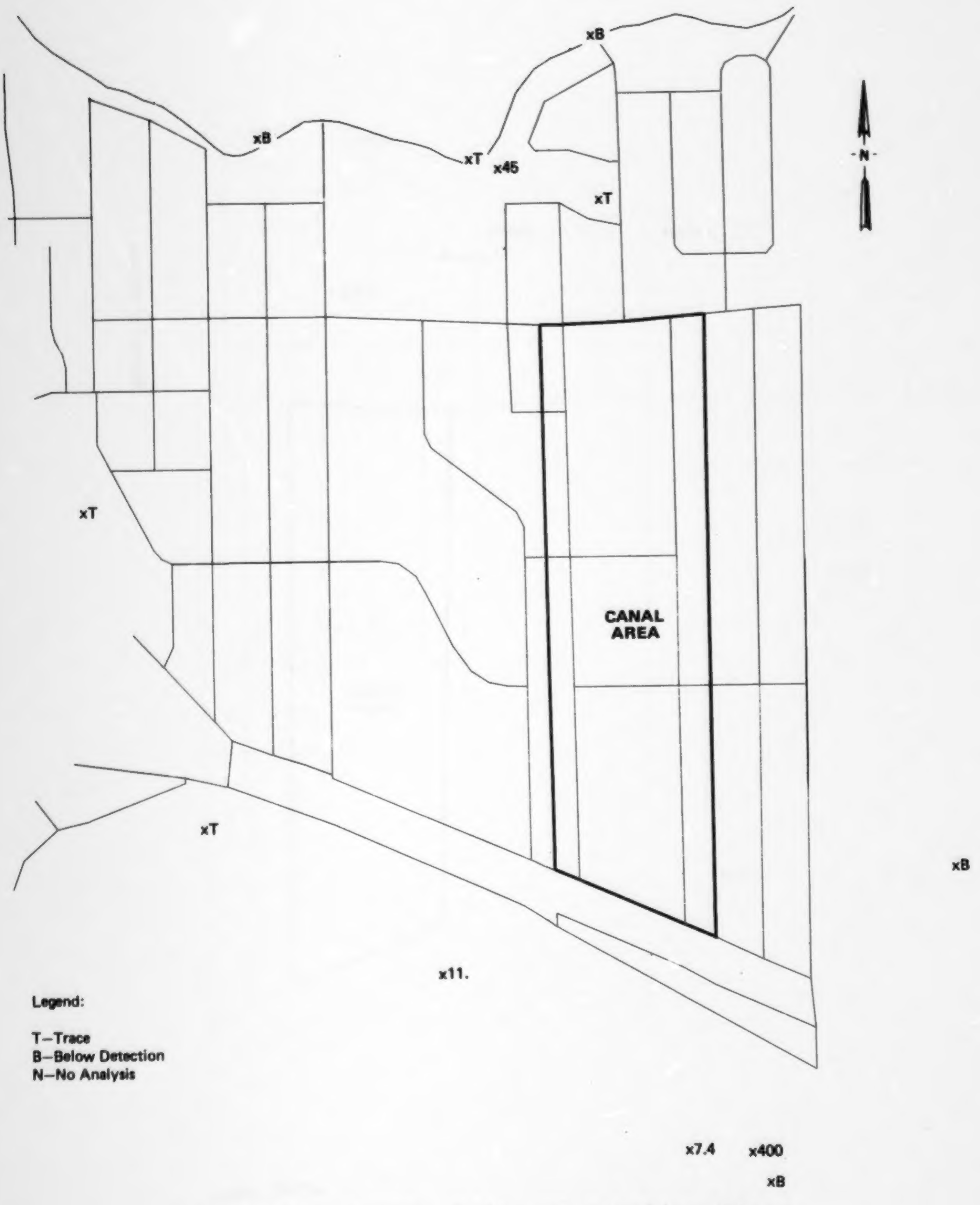

xB
xB
xT
x45
xT
N
xT
CANAL AREA
xT
xB
x11.
Legend:
T—Trace
B—Below Detection
N—No Analysis
x7.4
x400
xB

Figure 43. Stream Sediment Sampling Sites, Benzene, Maximum Concentrations (micrograms per kilogram, ppb).

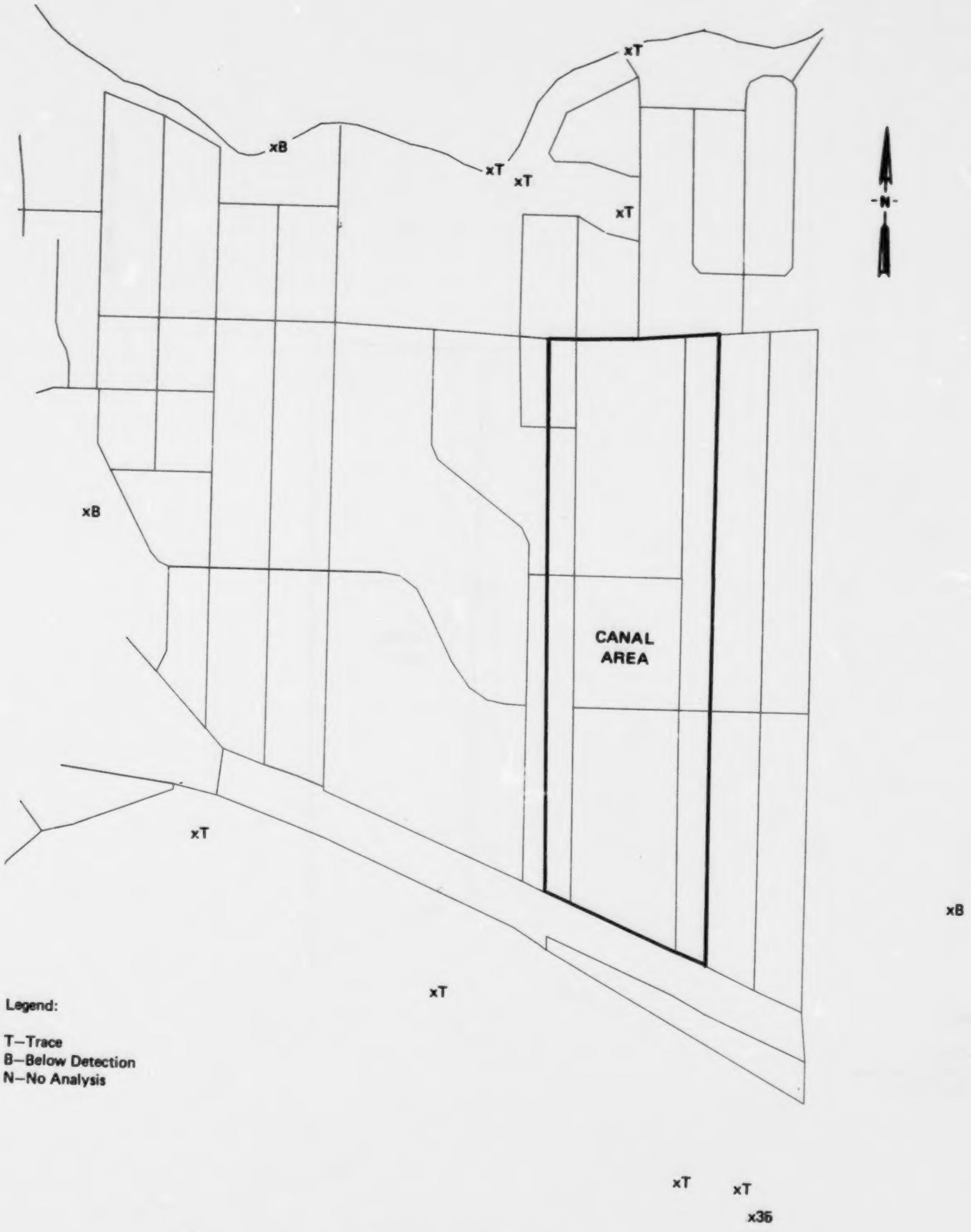

xT
xB
xT
xT
xT
N
xB
CANAL
AREA
xT
xB
xT
Legend:
T—Trace
B—Below Detection
N—No Analysis
xT
xT
x35

Figure 44. Surface Water Sampling Sites, Toluene, Maximum Concentrations (micrograms per liter, ppb).

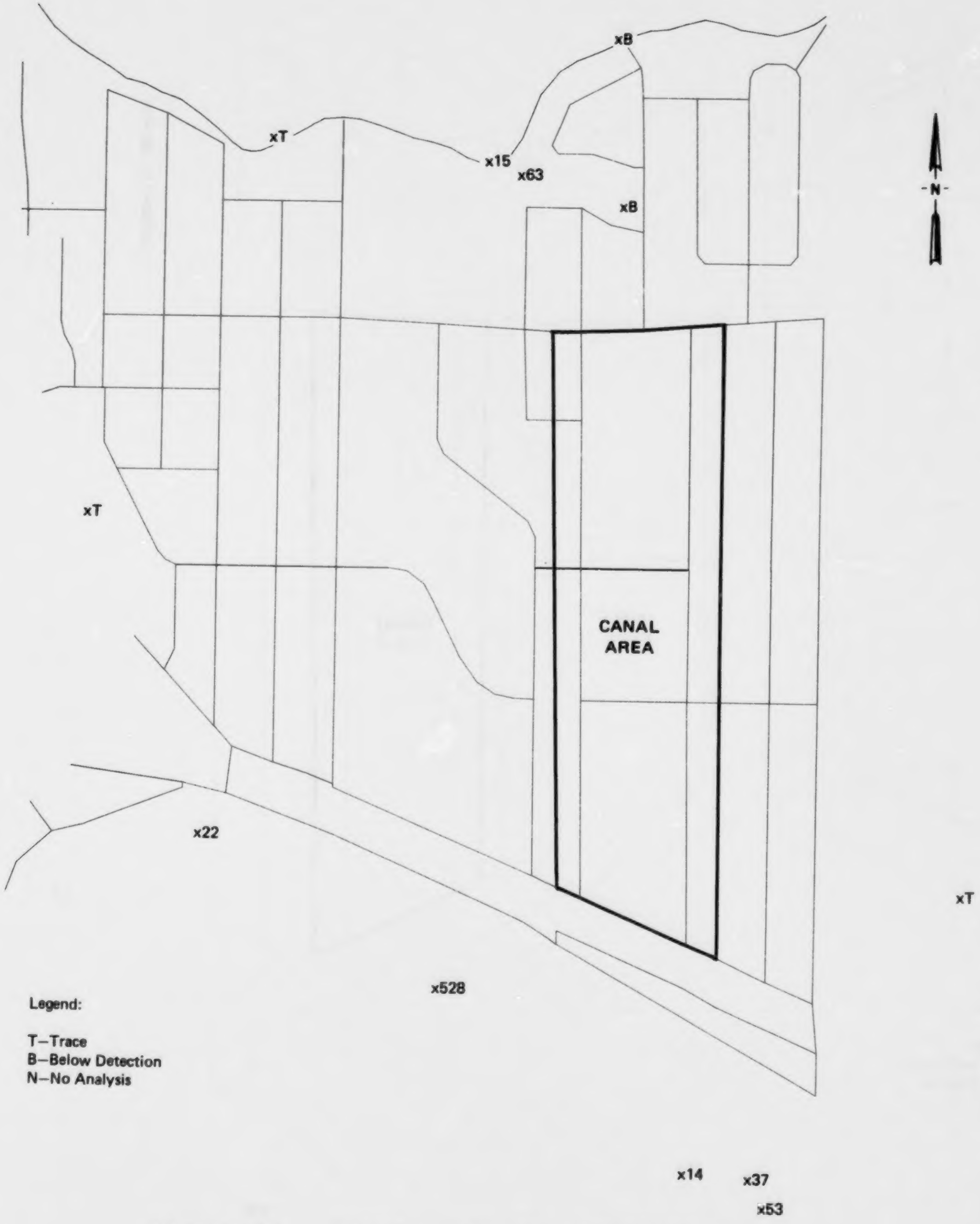

xB
xT
x15
x63
xB
N
CANAL
AREA
xT
x22
xT
x528
Legend:
T—Trace
B—Below Detection
N—No Analysis
x14
x37
x53

Figure 45. Stream Sediment Sampling Sites, Toluene, Maximum Concentrations (micrograms per kilogram, ppb).

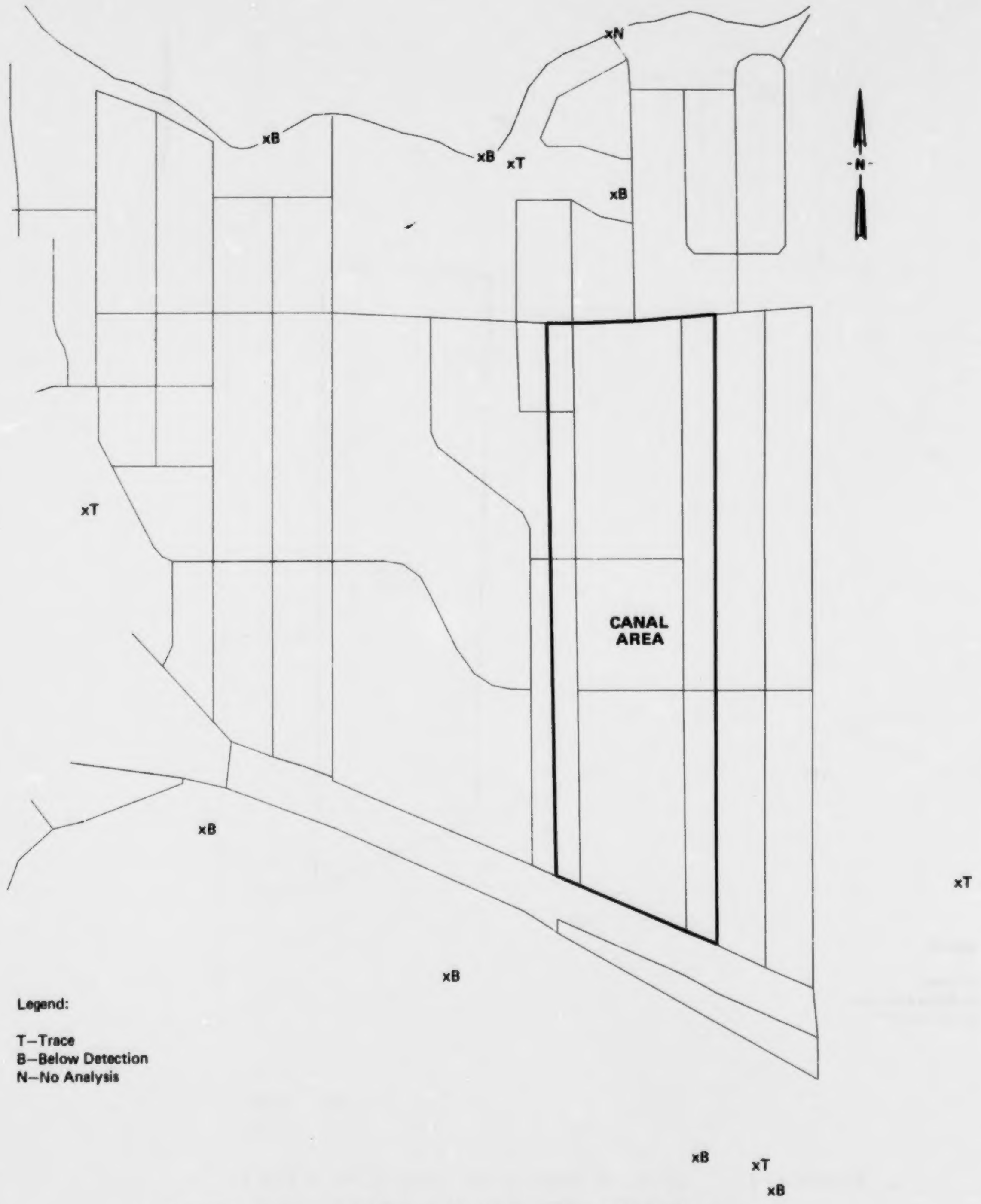

xN
xB
xB
xT
xB
N
xT
CANAL AREA
xB
xT
xB
Legend:
T—Trace
B—Below Detection
N—No Analysis
xB
xT
xB

Figure 46. Surface Water Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per liter, ppb).

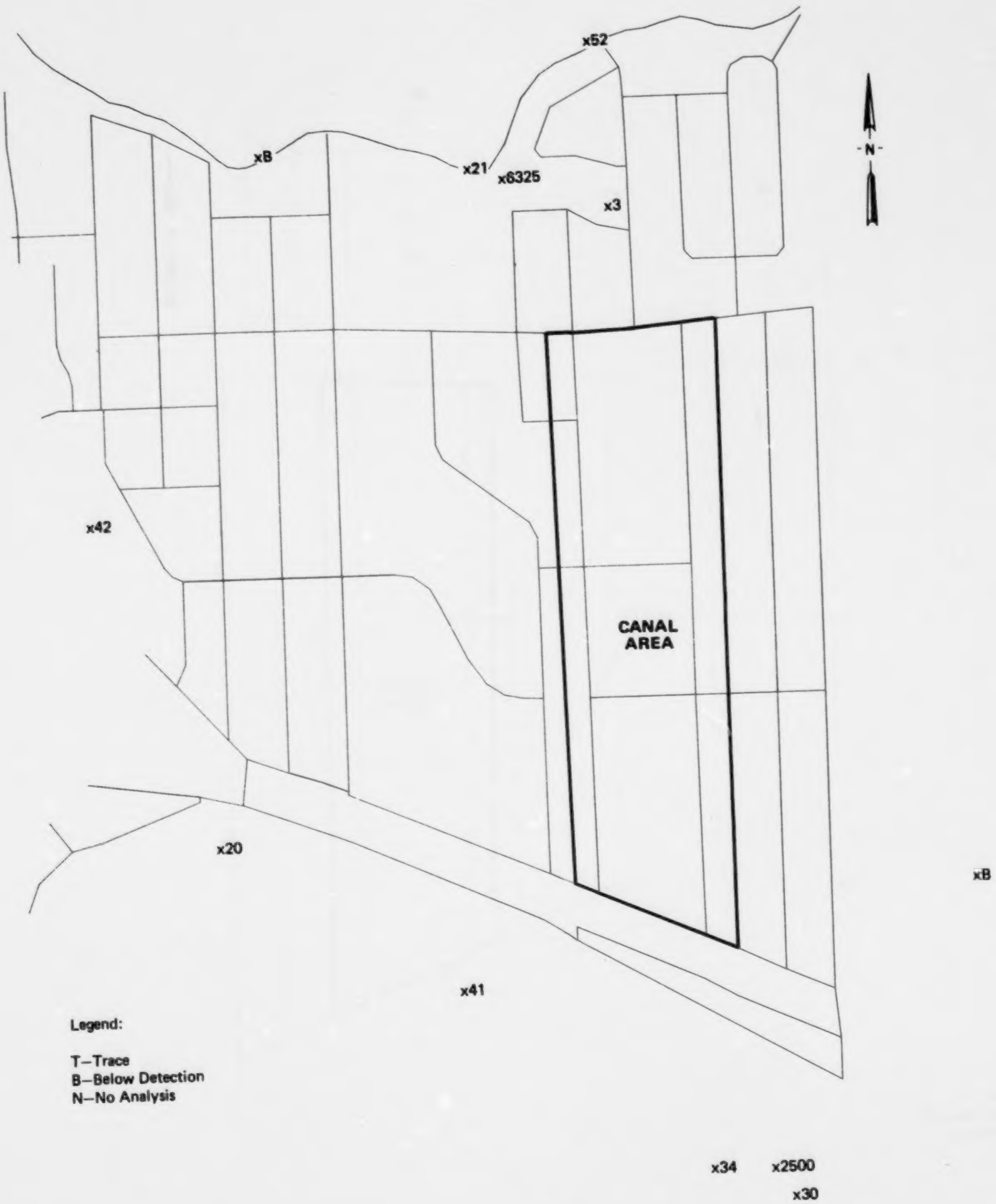

x52
xB
x21
x6325
x3
N
CANAL AREA
x42
x20
xB
x41
Legend:
T—Trace
B—Below Detection
N—No Analysis
x34
x2500
x30

Figure 47. Stream Sediment Sampling Sites, γ-BHC, Maximum Concentrations (micrograms per kilogram, ppb).

program are presented. Additional surface water and stream sediment figures are presented in Volume III. In Figure 43 the results obtained for benzene in stream sediment samples are presented; in Figures 44 and 45 the results for toluene are presented for water and sediment samples, respectively; and in Figures 46 and 47, the results for α-BHC are presented. As can be seen in these figures, clear evidence of Love Canal-related contamination was found in Black Creek at, and downstream from, the 96th Street storm sewer outfall in the creek (sites 04015 and 04016). Because a Canal Area-related storm sewer outfall in Black Creek is also located in the underground portion of the creek between 101st and 102nd Streets, the closest point to the outfall that could be sampled was located downstream where Black Creek surfaces near 98th Street (site 04014). At this site too, evidence of Love Canal-related contamination was found. Specific details of the results obtained may be found in Volume II.

The evidence obtained near the 102nd Street outfall (site 97543) was also suggestive of the transport of contaminants from Love Canal. However, due to the proximity of the 102nd Street landfill, it was not possible to identify the contamination present at the site as due totally to the direct migration of contaminants from Love Canal. In particular, substantial concentration levels of identical contaminants were found in sediment samples collected upstream from the outfall. In passing, it should be noted that contaminated sediment was also found in both Cayuga Creek and the Little Niagara River. Given the limited evidence identifying the existence of mechanisms for the direct migration of Love Canal-related contaminants to these waterways, it cannot be concluded unequivocally that the source of contamination is Love Canal.

Before concluding this portion of the report, it may be useful to review the major results obtained thus far. To begin with, a clear, consistent pattern of ground-water, soil, and sump contamination was found in certain ring 1 residences. In addition, both the sanitary and storm sewer lines constructed immediately adjacent to Love Canal were found to be contaminated and were continuing to contribute to the distant transport of contaminants from Love Canal. Finally, the evidence obtained also suggested that creeks and rivers in the immediate vicinity of Love Canal-related storm sewer outfalls, and for some undetermined distance downstream from those outfalls, were contaminated by the direct migration of contaminants from the former canal through the storm sewer system.

4.2.6 Air Contamination

The air monitoring program was designed to determine the spatial and temporal variability in airborne contamination caused by pollutants migrating from the former canal. To accomplish this goal, the selection of a sufficient number of air monitoring sites and sampling periods had to be balanced against time, budgetary, and logistical constraints. Consequently, a sampling design was selected for air monitoring purposes that involved partitioning the Declaration Area into homogeneous units (Figure 4). The sampling area scheme adopted was intended to categorize the residences of the Declaration Area according to characteristics that may have been related to the migration of contaminants from Love Canal, including distance and direction from the Canal Area, and proximity to local creeks (Figure 3). In addition, criteria established for the selection of specific residences within each sampling area included the following: (1) adjacency to known former swales; (2) adjacency to historically wet or dry areas (that is, areas where standing water tended to accumulate); and (3) all sites had to be unoccupied throughout the duration of the study period.

A total of 61 sites in the Declaration and Canal Areas, and 4 control sites, were selected for regular air monitoring purposes (Figure 48). The air monitoring control sites were: site 99020, located on Stony Point Road, Grand Island; site 99021, located on West River Parkway, Grand Island; site 99022, located on Pierce Road, Niagara Falls; and site 99023, located on Packard Road, Niagara Falls. At each of the regular air monitoring sites, up to 13 daytime air sampling campaigns (consisting of integrated 12-hour sampling periods) were conducted. Three special air monitoring research studies, an air pollutant transport study, a sump/basement-air study and an occupied/unoccupied study were also conducted at Love Canal. The data from these special studies are included in Volume II, but are not considered in detail in this report.

Prior to the initiation of the air monitoring program, each sampling site was cleared of certain household items, such as cleaning products, aerosol cans, and all other organic consumer products, and was forced-air ventilated for 4 hours. Throughout the duration of the study, all entry points in each air monitoring residence were secured with evidence tape, and doors were padlocked to prohibit unauthorized entrance and potential tampering with sampling equipment.

It should be pointed out that the sampling design used for indoor air monitoring purposes was based, in part, on the results obtained from previous air monitoring studies conducted by various organizations at Love Canal. These previous studies suggested that (among other things) relatively large variations in day-to-day indoor air pollutant concentration levels were likely to be observed, and that such variations were likely to be caused by a number of factors. For example, variability in indoor air pollutant concentration levels could be influenced by: (1) rapid

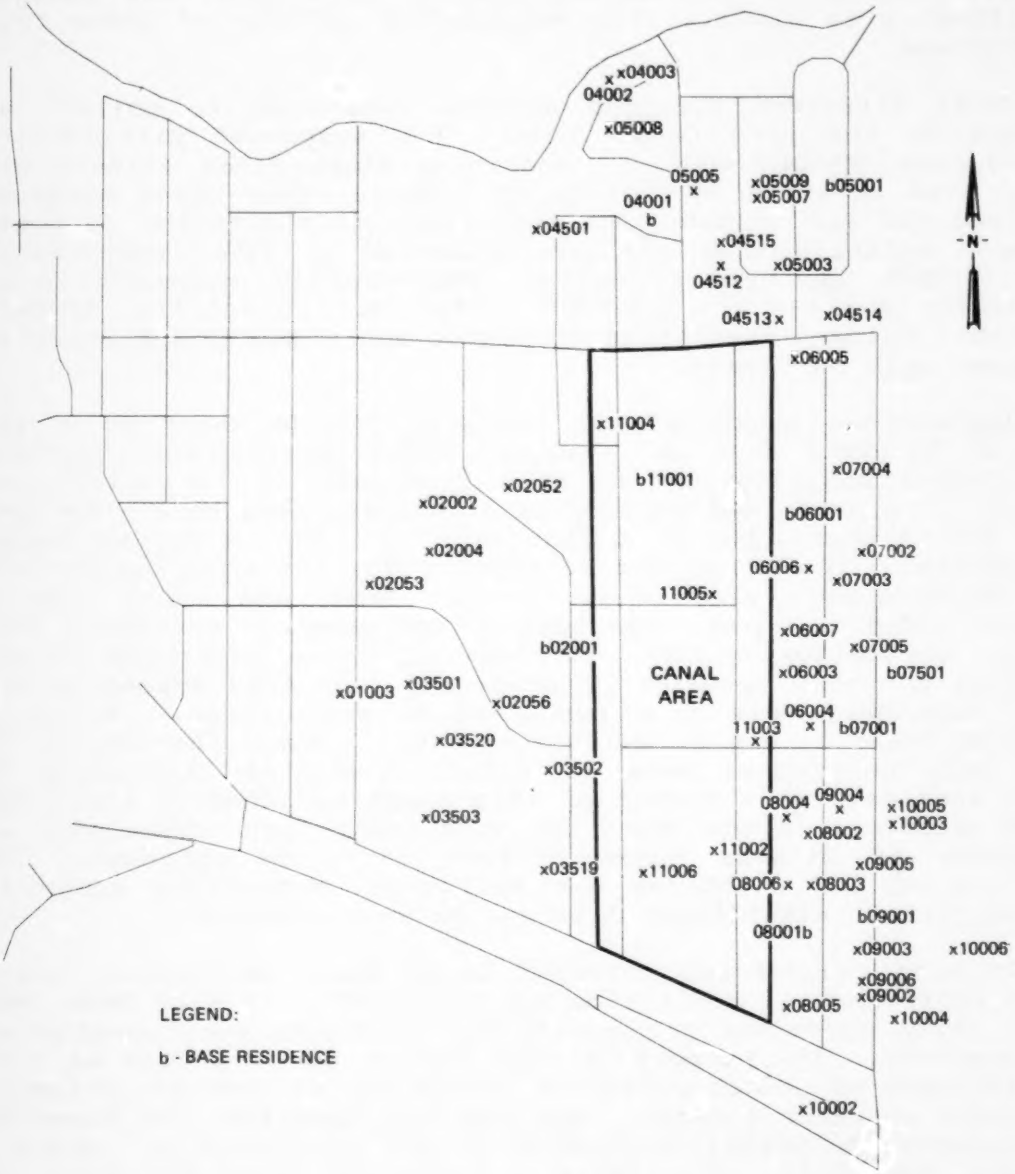

x04003
04002
x05008
05005
x05009
x05007
b05001
04001
b
x04501
x04515
x05003
04512
04513 x
x04514
N
x06005
x11004
b11001
x07004
x02052
x02002
b06001
x02004
x07002
06006 x
x07003
x02053
11005x
x06007
x07005
b02001
CANAL AREA
x06003
b07501
x01003
x03501
x02056
06004
11003
b07001
x03520
x03502
09004
08004
x10005
x10003
x08002
x03503
x11002
x09005
x03519
x11006
08006 x
x08003
b09001
08001b
x09003
x10006
x09006
x09002
x08005
x10004
x10002
LEGEND:
b - BASE RESIDENCE

Figure 48. Air Sampling Site Codes.

fluctuations in ambient concentrations; (2) the use or presence of certain consumer products in a residence (particularly when occupied residences are sampled); and (3) differences in the sampling and analytical methodologies used for monitoring purposes. The air monitoring program employed at Love Canal was designed specifically to minimize the confounding effects of these types of problems.

Three different sampling devices were used to collect air samples in the Love Canal area. For suspended particulates, high-volume (HIVOL) samplers employing glass fiber filters were used. The relative volatility of organic vapor phase compounds required the use of two solid sorbents for monitoring purposes. The more volatile compounds were collected on TENAX; polyurethane foam (PFOAM) was used to collect semivolatile compounds in air and to monitor for 2,3,7,8-TCDD. (See Section 4.3.5). Appendix A of this Volume lists those compounds and elements for which air analyses were performed.

High-volume samplers were operated for 24 hours at a flow rate of 50 cubic feet per minute. TENAX samplers were operated for 12-hour sampling periods at a flow rate of 30 cubic centimeters per minute, and polyurethane foam samplers were also operated for 12 hours, but at a flow rate of 1,250 cubic centimeters per minute. On each of the 13 regular daytime sampling periods, all samplers were started at 6 a.m. TENAX and PFOAM sampling periods ended at 6 p.m.; the high-volume samplers continued until 6 a.m. the following day. A total of three nighttime 12-hour sampling periods, immediately preceding regularly scheduled daytime campaigns, were also conducted at some sites. Nighttime sampling began at 6 p.m. and lasted until 6 a.m.; the regular 12-hour daytime samples were collected immediately following the night samples. As a result of this sampling schedule there were three occasions in the study for which night/day comparisons and estimates of 24-hour concentrations could be obtained. The findings of the night/day air pollution comparisons study revealed that no significant differences were observed.

In nine residences, referred to as base residences, multimedia environmental monitoring was performed. In each base residence three different air monitoring locations were sampled simultaneously. The purpose of this design was to permit an overall estimate of indoor pollutant levels and to identify potential pollutant entrance sources. One sampling location, the basement, was intended to permit estimation of the concentration levels of organic compounds potentially evaporating from the sump and through foundations walls. Duplicate samples were collected at a second sampling location, the first floor living area, was intended to permit estimation of pollutant levels occurring in the most commonly occupied area of the residence, and for quality assurance purposes. And finally, a sampling location immediately outside the residence, just above ground level, was selected to permit estimation of ambient concentration levels of monitored substances. All three sampling locations at base residences contained both TENAX and PFOAM samplers. The outside site also contained a HIVOL sampler. The remaining residences in each sampling area, and the four control area homes, were sampled only in the living area.

In Table 10, the statistically significant results obtained from the air monitoring program are presented. More extensive tabulations of air monitoring data, describing the extent and degree of air contamination found in the general Love Canal area, are presented in Volume III of this report.

As can be seen from the results presented in Table 10, the extent of indoor air contamination in the Declaration Area was significantly ($\alpha=0.10$, one-tailed) greater than at control sites for o-chlorotoluene (in living area samples), and o-dichlorobenzene (also in living area samples). It can also be seen in Table 10 that the only other statistically significant difference found was for chlorobenzene in living area air samples, comparing the Canal Area to the Declaration Area.

The reader is cautioned to interpret these few significant results carefully, and to consider the following points. First, apart from three compounds, detection percentages were low overall. For the three compounds detected most frequently, benzene, toluene, and 1,1,2,2-tetrachloroethylene, a known contamination problem (described in Appendix E) associated with the sampling collection medium TENAX was observed (detection percentages for these compounds on TENAX were, respectively, 95, 86, and 77 percent). Second, relatively high detection percentages should not be equated with the occurrence of relatively high concentration levels. Third, the detection percentages were not found to display any consistent patterns of spatial variability (for example, increased detection was not related to decreased distance from Love Canal). (See Volume III for appropriate tables). Fourth, due to the large number of sequential statistical comparisons that were performed, care must be exercised (because of increased Type I errors) in the interpretation of the few results observed that satisfied a nominal level of significance. Finally, the lack of internal consistency (Table 10) exhibited by the few significant results obtained suggests that these outcomes may be due to chance.

In order to characterize the degree of air contamination found in the Declaration and Canal Areas, the monitoring data were subjected to a number of different statistical analyses. First, at each site the maximum observed concentrations (across all sampling campaigns) of the organic compounds monitored were determined according to source (that is, TENAX or PFOAM) and location. Second, the concentration levels of the organic

TABLE 10. SIGNIFICANT DIFFERENCES OBSERVED IN THE EXTENT OF AIR CONTAMINATION AT LOVE CANAL

	Sampling Location Comparison[†]			
	Outdoors	Basement	Living Area	
Compound	Canal-Declaration	Canal-Declaration	Canal-Declaration	Declaration-Control
o-Chlorotoluene	No	No	No (α=0.104)	Yes
o-Dichlorobenzene	No	No	No	Yes
Chlorobenzene	No	No	Yes	No

	Percent Detect (Number of Samples)		
	Living Area		
Compound	Declaration	Control	Canal
o-Chlorotoluene	27.5 (461)	6.7[‡] (30)	37.0 (54)
o-Dichlorobenzene	43.4 (459)	10.0[‡] (30)	24.1 (54)
Chlorobenzene	1.3 (460)	0.0[‡] (31)	7.4 (54)

[†] Comparisons are based on a one-tailed difference of proportions test (α=0.10), using Fisher's exact test, for the areas indicated, and in the order presented.

[‡] The reported percent does not differ significantly from zero at the α=0.05 level.

compounds monitored at each site were reviewed (according to sampling campaign) for temporal trends. Third, the median concentrations of the organic compounds monitored at each site were computed according to source and location. And finally, the median concentrations of the organic compounds monitored at each site were computed according to sampling campaign. Because quantifiable results for organic compounds monitored on PFOAM were so infrequent, they are not presented in this report. The reader interested in the results obtained from both PFOAM and HIVOL monitoring should consult Volume III for details.

The remainder of this section discusses the air monitoring results for the three most frequently detected compounds; benzene, toluene, and 1,1,2,2-tetrachloroethylene. It should be noted once again that these three compounds are known contaminants of the collection medium TENAX, and therefore must be interpreted in the context of the discussion presented in Appendix E (especially in Table E-4). No other organic compounds were detected frequently enough to permit additional discussion.

To illustrate the results obtained, the maximum concentrations of benzene obtained from air monitoring conducted at each site, across all regular air monitoring campaigns, are presented (respectively) for outside, living area, and basement air monitoring locations in Figures 49 through 51. Additional figures of maximum air pollutant concentrations (for selected compounds) are presented in Volume III. In Table 11, the three highest concentrations of certain organic compounds found in air are reported according to sampling location, and by Declaration, Control, and Canal Areas.

A review of the results presented in Figures 49 through 51, the values reported in Table 11, and the additional tables and figures presented in Volume III, revealed that no consistent patterns were found in the maximum values of air contaminants which could be directly attributed to the migration of those compounds from Love Canal. In light of the findings presented in Section 4.1 and other portions of Section 4.2, and the remedial actions performed at the site, these results are consistent with the implications of the hydrogeologic program and the other data obtained from the monitoring program.

Even though maximum concentration levels are often of considerable interest to individuals, because in some way they may be thought to represent "worst case" estimates of environmental contamination, problems of statistical interpretation exist. Such problems exist because both the occurrence and the reliability of the obtained maximum values may be plagued by measurement problems. To illustrate this point, it is often the case that maximum

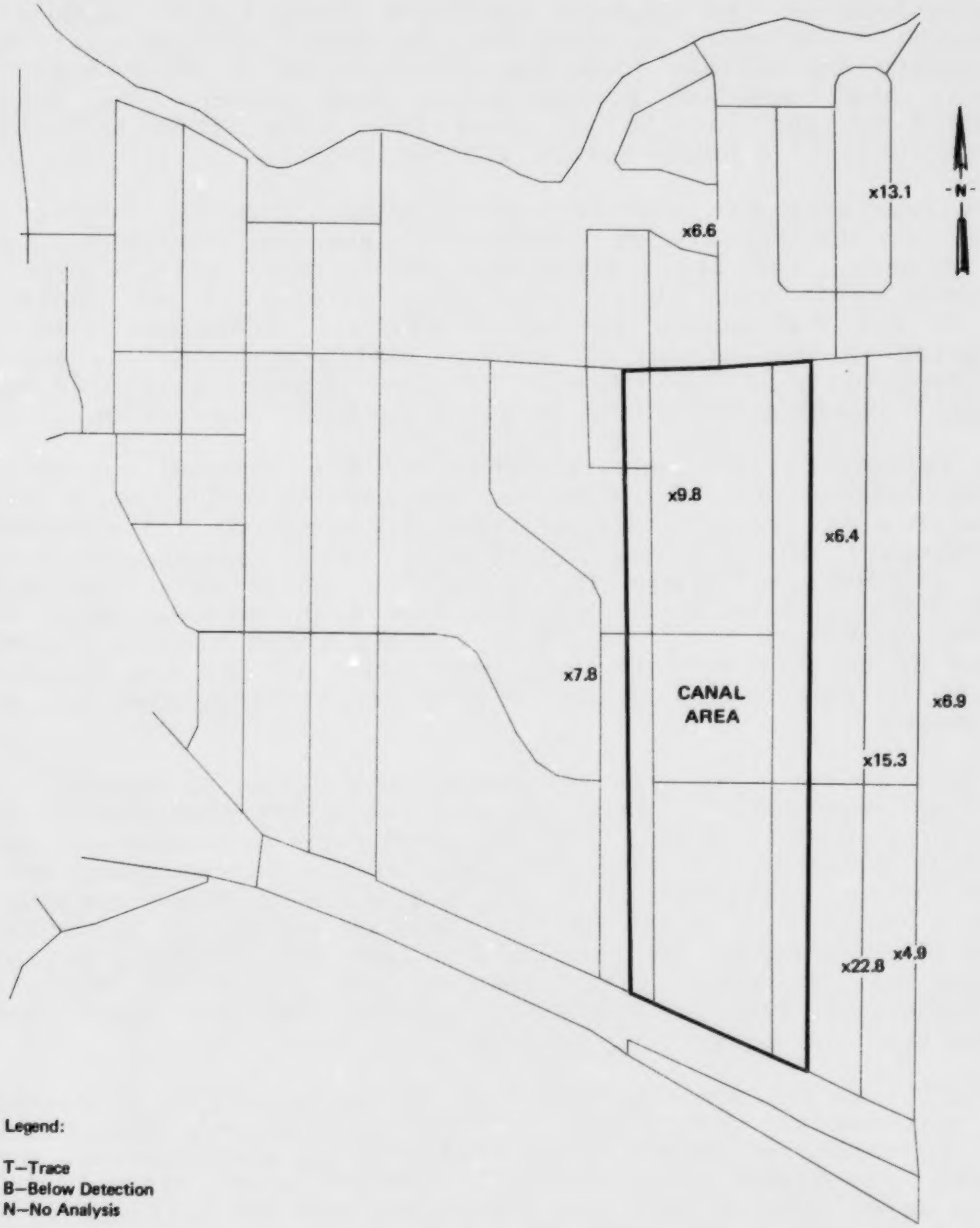

x13.1
N
x6.6
x9.8
x6.4
x7.8
CANAL AREA
x6.9
x15.3
x22.8
x4.9
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 49. Outside Air Sampling Sites, Benzene, Maximum Concentrations (micrograms per cubic meter).

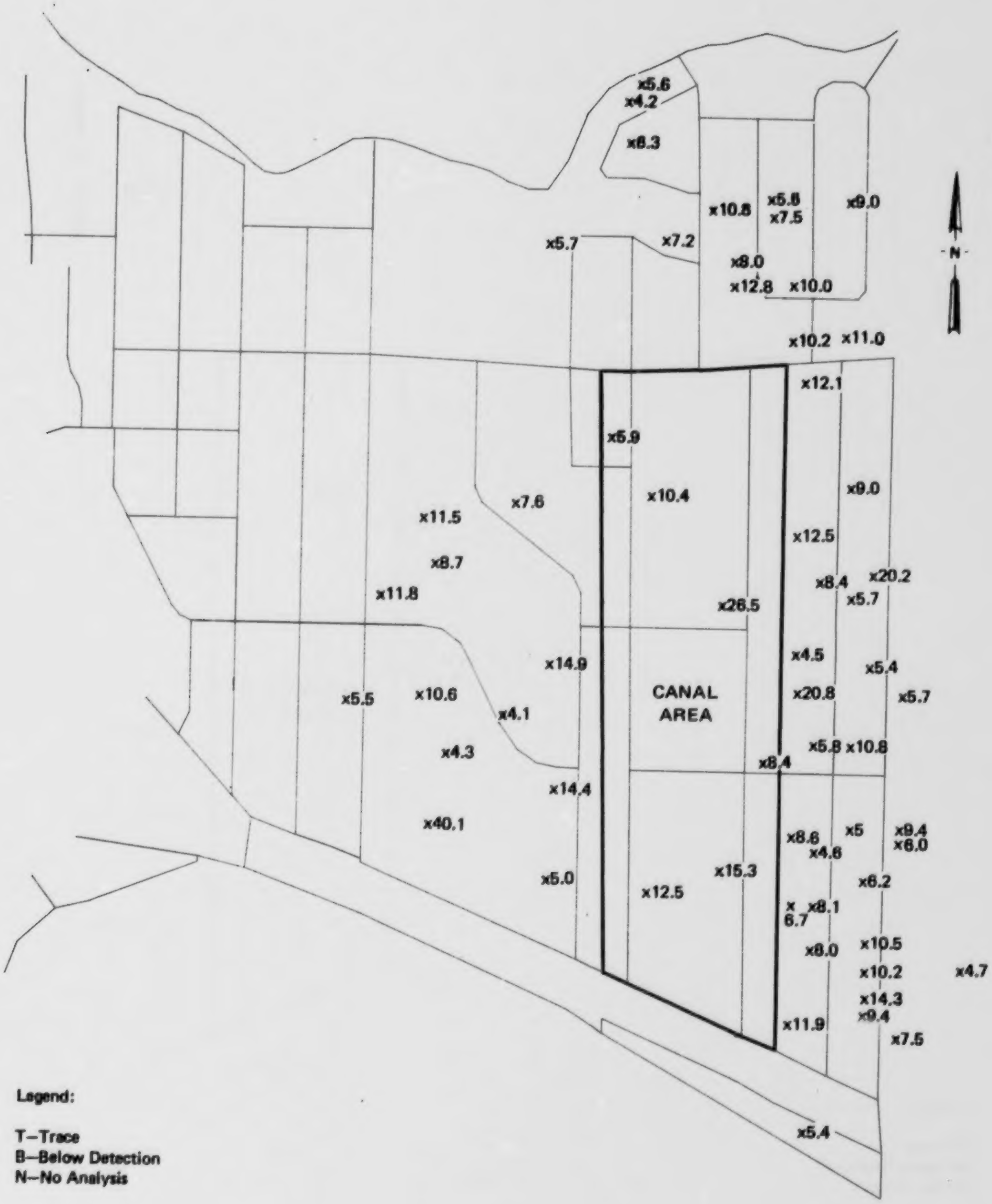

x5.6
x4.2
x6.3
x10.8
x5.8
x7.5
x9.0
x5.7
x7.2
x8.0
x12.8
x10.0
N
x10.2
x11.0
x12.1
x5.9
x10.4
x9.0
x11.5
x7.6
x12.5
x8.7
x8.4
x20.2
x11.8
x26.5
x5.7
x14.9
x4.5
x5.4
CANAL AREA
x5.5
x10.6
x20.8
x5.7
x4.1
x4.3
x5.8
x10.8
x8.4
x14.4
x40.1
x8.6
x5
x9.4
x6.0
x4.6
x15.3
x5.0
x12.5
x6.2
x 6.7
x8.1
x8.0
x10.5
x10.2
x4.7
x14.3
x9.4
x11.9
x7.5
x5.4
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 50. Living Area Air Sampling Sites, Benzene, Maximum Concentrations (micrograms per cubic meter).

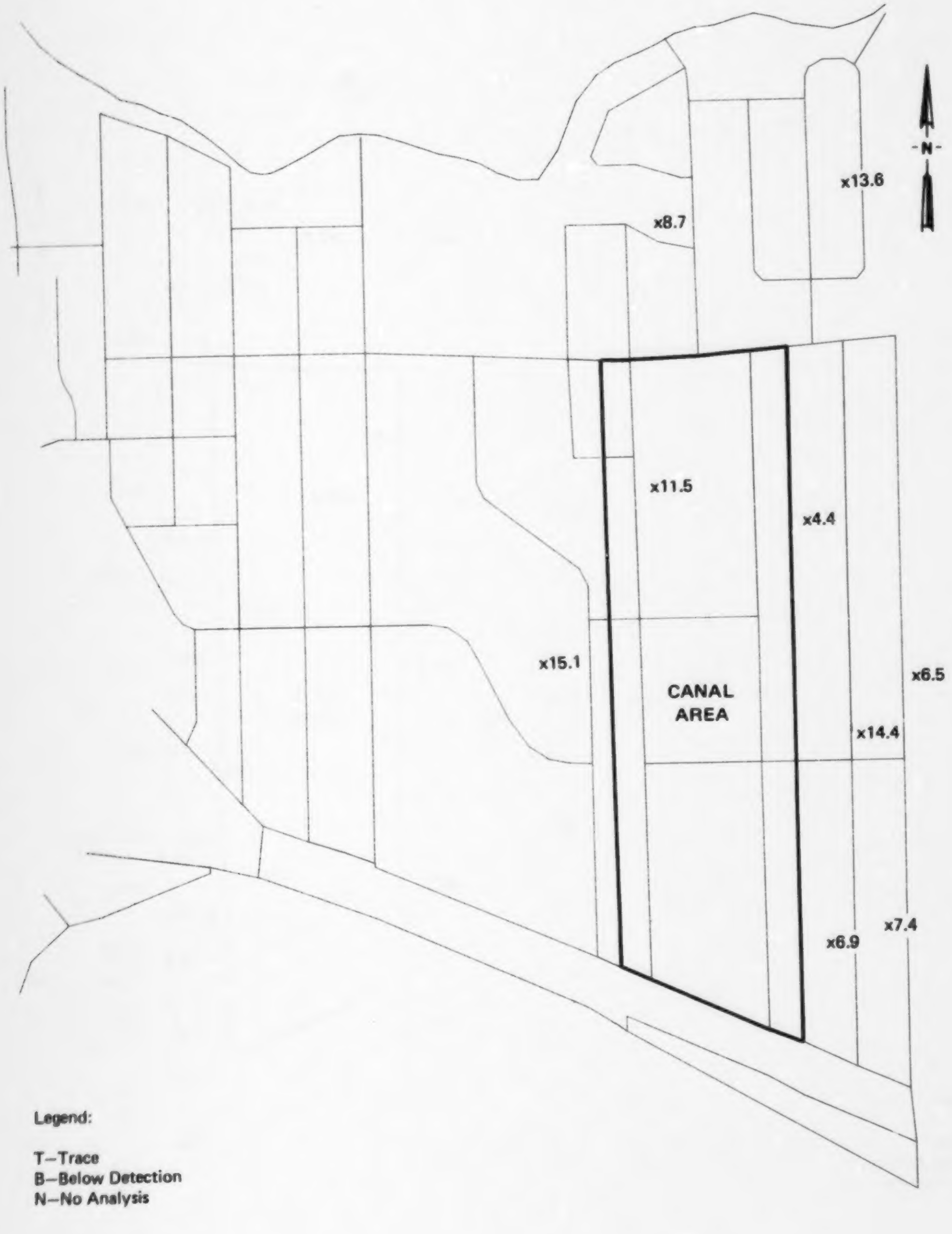

-N-
x13.6
x8.7
x11.5
x4.4
x15.1
CANAL AREA
x6.5
x14.4
x6.9
x7.4
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 51. Basement Air Sampling Sites, Benzene, Maximum Concentrations (micrograms per cubic meter).

TABLE 11. THREE HIGHEST CONCENTRATIONS OF SELECTED COMPOUNDS OBSERVED IN REGULAR AIR MONITORING (MICROGRAMS PER CUBIC METER)[†]

	Living Area			Basement		Outdoors	
Substance	Declaration Area	Control	Canal Area	Declaration Area	Canal Area	Declaration Area	Canal Area
Benzene	40,21,20	39,27,21	27,15,13	15,14,14	12,8,6	23,15,13	10,9,6
Carbon tetrachloride	77,45,16	4,T,B	4,4,T	11,5,3	B,B,B	4,3,3	4,B,B
Chlorobenzene	3,3,T	B,B,B	3,T,T	3,B,B	B,B,B	3,T,B	B,B,B
o-Chlorotoluene	8,6,6	6,T,B	4,2,2	5,4,4	2,T,T	4,4,4	T,T,B
p-Chlorotoluene	5,5,4	T,T,B	3,2,2	5,4,4	2,T,B	4,4,3	B,B,B
o-Dichlorobenzene	68,64,64	T,T,T	6,5,T	9,9,6	T,T,B	T,T,T	T,B,B
p-Dichlorobenzene	25,23,21	4,T,T	T,T,T	17,5,4	B,B,B	T,B,B	B,B,B
1,1,2,2-Tetrachloroethylene	104,64,60	142,108,68	89,44,32	158,40,37	30,27,9	20,20,19	44,36,11
Toluene	92,90,68	68,52,47	57,32,27	57,48,42	32,19,18	19,18,14	27,23,12

B: Below detection
T: Trace concentration

[†] The reader is cautioned to interpret carefully the extreme values reported in this table, and to not ascribe statistical significance to these results.

concentrations are reported by only one analytical laboratory and on one particular date, whereas other analytical laboratories may not report concentration levels anywhere near such maxima (and in some cases do not even report concentration levels above the limit of detection).

With this caveat aside, the reader may still choose to cautiously compare the values reported in Table 11 to the existing air pollution standards and recommended work-place limits identified in Appendix B of this Volume. Such a comparison reveals that the maximum concentrations observed at Love Canal were often orders of magnitude less than the corresponding workplace standards and recommended exposure limits. However, it must be acknowleged that the applicability of comparing workplace standards and limits (even after conservative adjustments are attempted) to residential exposure levels is unknown.

The air monitoring data obtained from Love Canal were also reviewed from a temporal (that is, sampling campaign) perspective. Typical examples of the results obtained from this effort, once again for benzene, are presented in Figures 52 and 53. In these two figures, the individual air monitoring results obtained from living area air samples collected in all Canal Area and control sites sampled are presented in conjunction with the sampling campaign date.

As can be seen from the results displayed in Figures 52 and 53, some variability in concentration levels was observed across time. However, most of the variability observed in the sample results could be accounted for by measurement errors. On the basis of other statistical analyses conducted with these data, no significant functional relationships were observed between the obtained concentration levels and such factors as distance from Love Canal, wet/dry residences, proximity to a former swale, diurnal/nocturnal sampling, and sampling campaign. In addition, the infrequent occurrence and isolation of the (relatively) extreme values present in the data displayed in Figures 52 and 53 should be noted.

The air monitoring data obtained from Love Canal were also considered in terms of the median concentration values that were observed. At each site regularly monitored, the median concentration value of all measurements for each substance monitored was determined. Three typical examples of the results obtained from this effort are presented in Figures 54 through 56. In these figures, the living area median concentrations for benzene, toluene, and 1,1,2,2-tetrachloroethylene (respectively) are displayed for each air site regularly monitored. As can be seen from the results displayed in Figures 54 through 56, no pattern of air contamination that was directly related to the migration of these compounds from Love Canal was found (highest median concentrations are indicated in the figures).

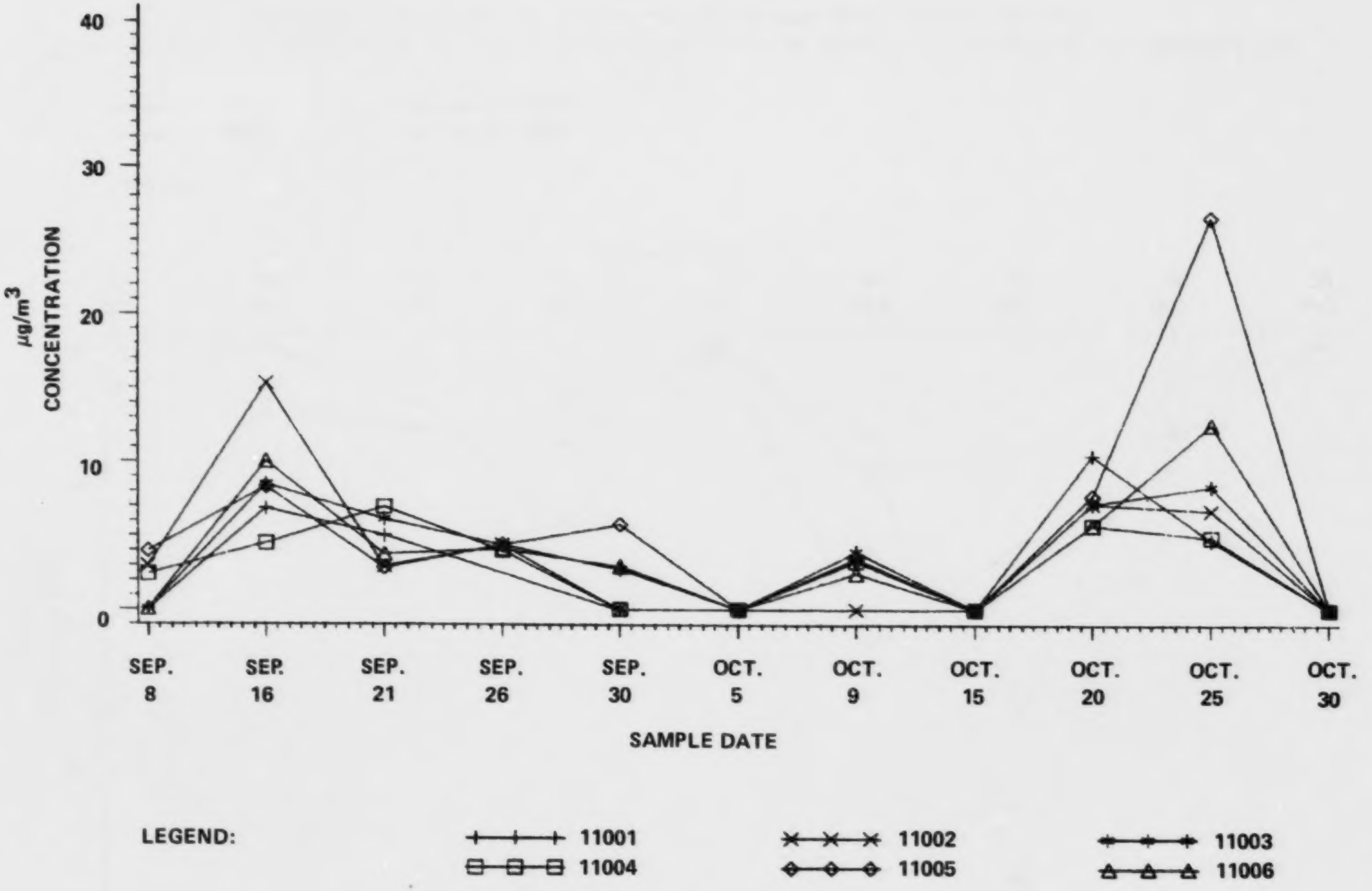


Figure 52. Concentration of Benzene in Living Area Air Samples Collected in Canal Area Residences (micrograms per cubic meter).

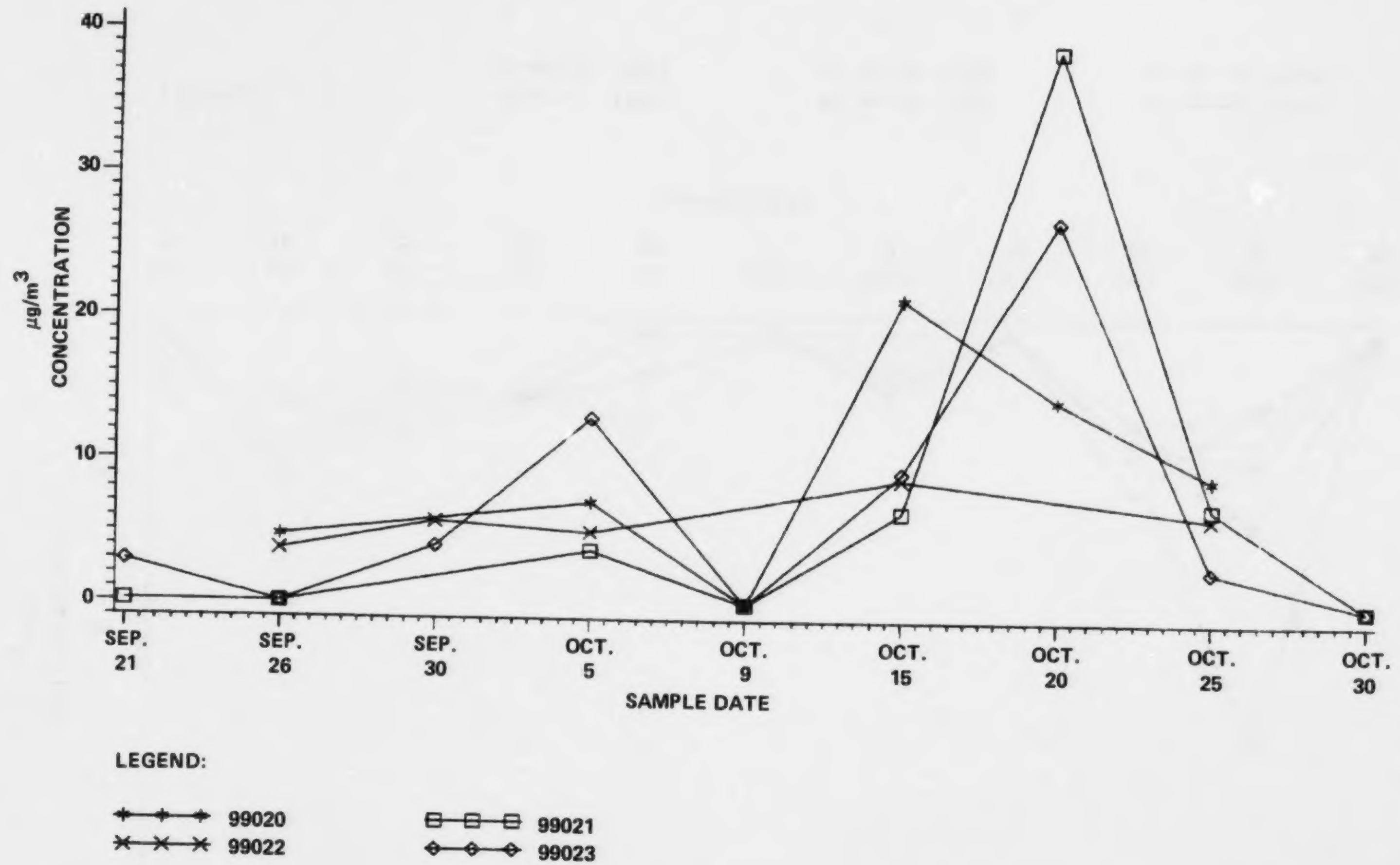


Figure 53. Concentration of Benzene in Living Area Air Samples Collected in Control Area Residences (micrograms per cubic meter).

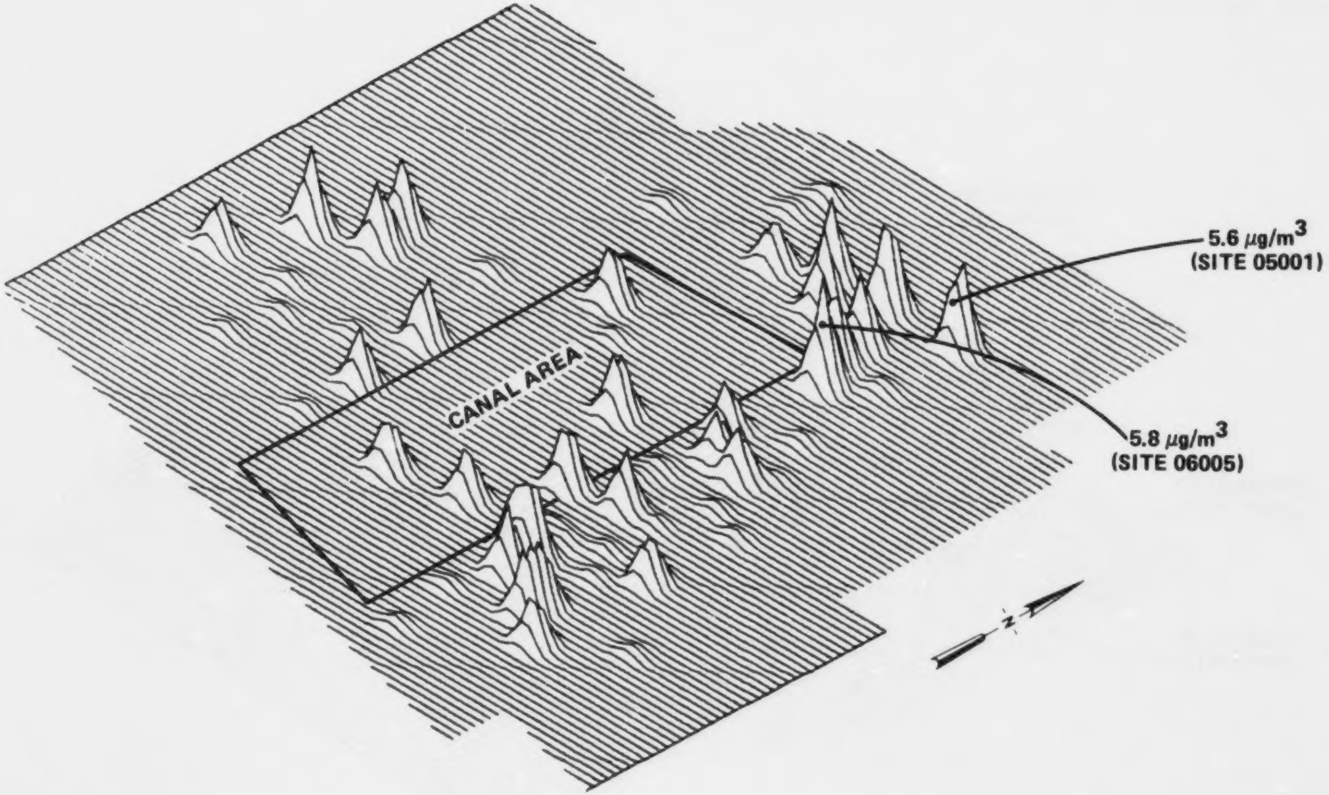


Figure 54. Median Concentration of Benzene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas (micrograms per cubic meter).

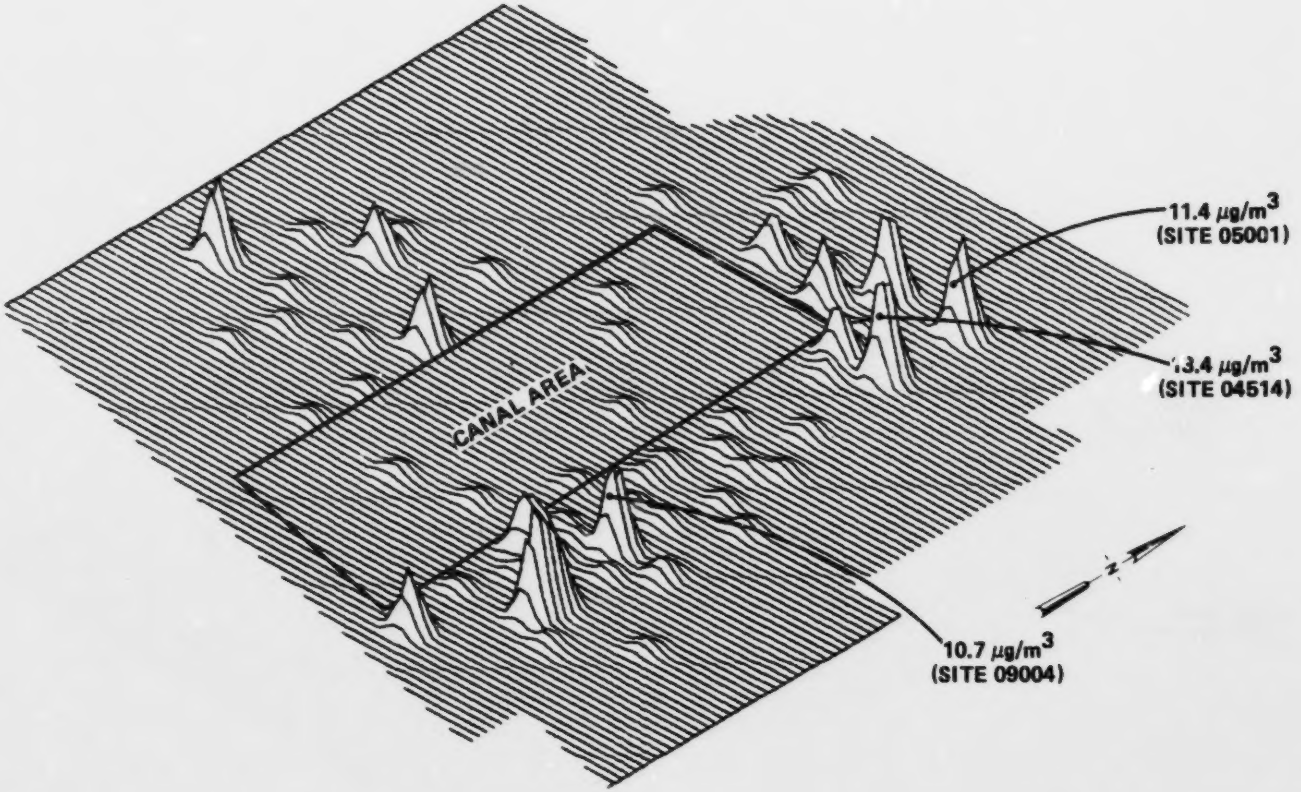


Figure 55. Median Concentration of Toluene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas (micrograms per cubic meter).

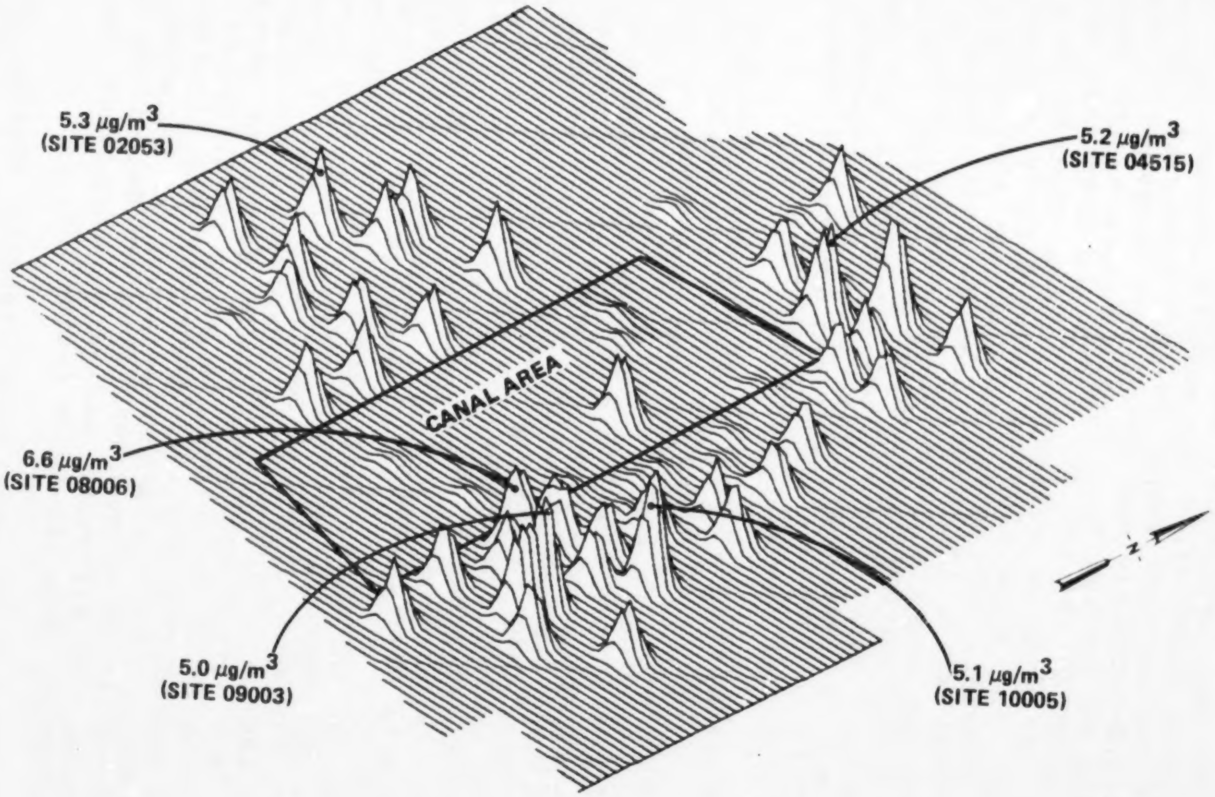


Figure 56. Median Concentration of 1,1,2,2-Tetrachloroethylene in Living Area Air Monitoring Sites Located in the Declaration and Canal Areas (micrograms per cubic meter).

Finally, the air monitoring data were considered in terms of the median concentration values that were observed in each sampling campaign. At each site regularly monitored, the median concentration value of all measurements for a compound, for each compound monitored, was determined according to sampling campaign. Three typical examples of the results obtained from this effort, incorporating the same compounds just discussed (benzene, toluene, and 1,1,2,2-tetrachloroethylene), are presented (respectively) in Figures 57 through 59. From a review of the results presented in Figures 57 through 59, it can be seen that except for living area air samples collected in the Control Area on October 20, 1980, the data displayed considerable across-time consistency. In passing, the reader is reminded that only four living area control sites were monitored for air contaminants during each sampling campaign, and greater variability in the computed median concentration values is to be expected. Furthermore, the relatively minor variability observed in the median concentrations across time was found to be non-systematic and attributable mainly to random fluctuations in ambient concentrations of these compounds throughout the general area.

The results from other detailed statistical analyses (not reported here) conducted on the Love Canal air monitoring data revealed the following. First, some intraresidence variability in living area air concentration levels was observed to be associated with changes in temperature. Second, the data suggested that in the Declaration Area some compounds were detected more frequently in living area samples than in samples collected outdoors. These compounds included: o-chlorotoluene (26 percent vs. 15 percent); o-dichlorobenzene (42 percent vs. 10 percent); p-dichlorobenzene (15 percent vs. 1 percent); and 1,1,2,2-tetrachloroethylene (93 percent vs. 82 percent). In addition, the median living area concentration of 1,1,2,2-tetrachloroethylene was higher than the outdoor median concentration (4 $\mu g/m^3$ vs. trace). Third, in the Declaration Area only one compound, o-chlorotoluene, was detected more frequently in living area samples than in basement samples (26 percent vs. 16 percent). Fourth, there was no indication that residences constructed in historically "wet" areas exhibited either different percentages of concentrations above the detection level or different median concentration levels than non-wet residences. And finally, there were no indications that residences existing in, or adjacent to, former swales exhibited either more frequent detections of compounds monitored, or different median concentration levels of compounds monitored, than non-swale residences.

The three special air monitoring research studies conducted at Love Canal provided limited evidence of the following additional results. First, airborne contaminants detected during the regular indoor air monitoring program were also detected (ordinarily at somewhat lower concentration levels) in the ambient air, and were transported from upwind. Second, highly

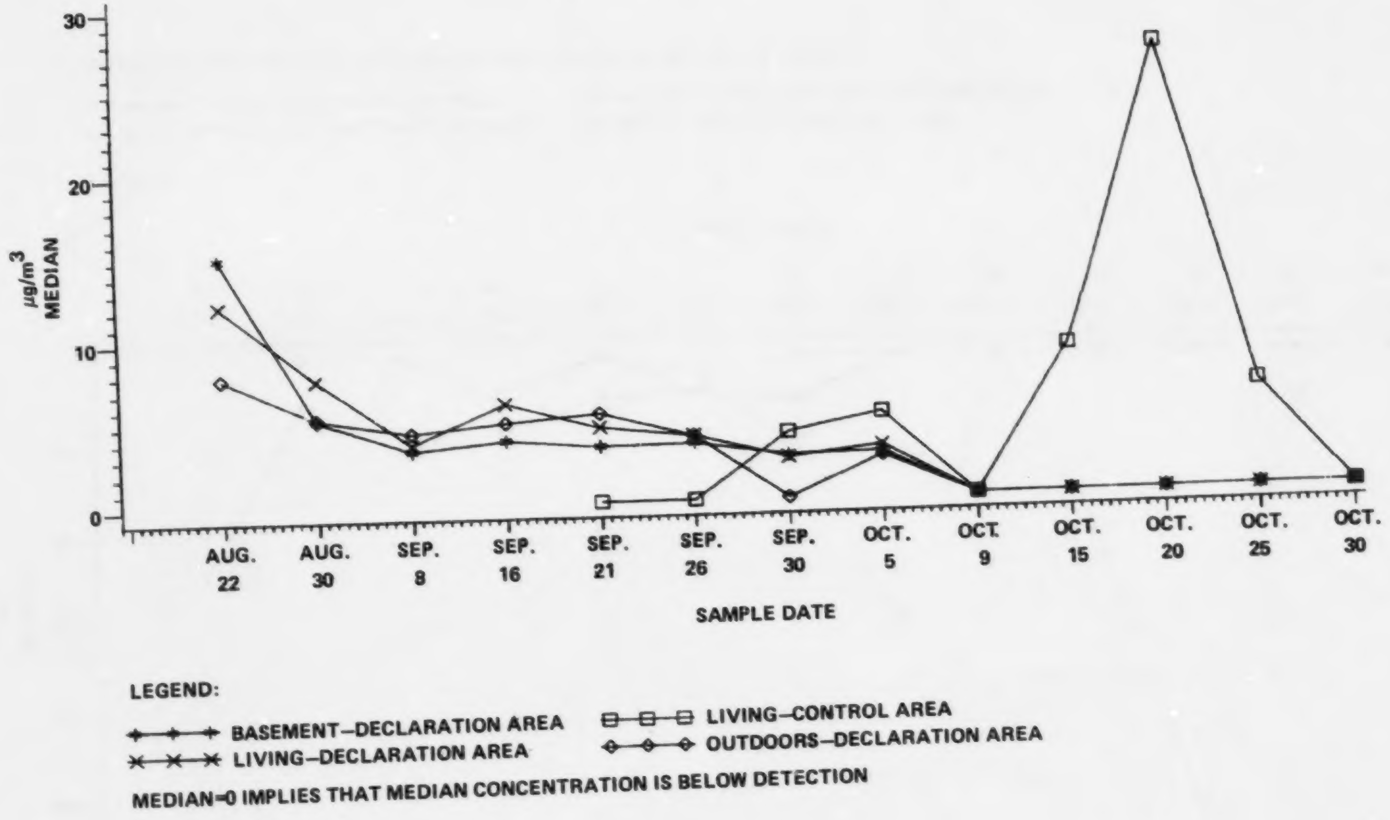


Figure 57. Median Concentration of Benzene Observed in Air for Each Sampling Campaign (micrograms per cubic meter).

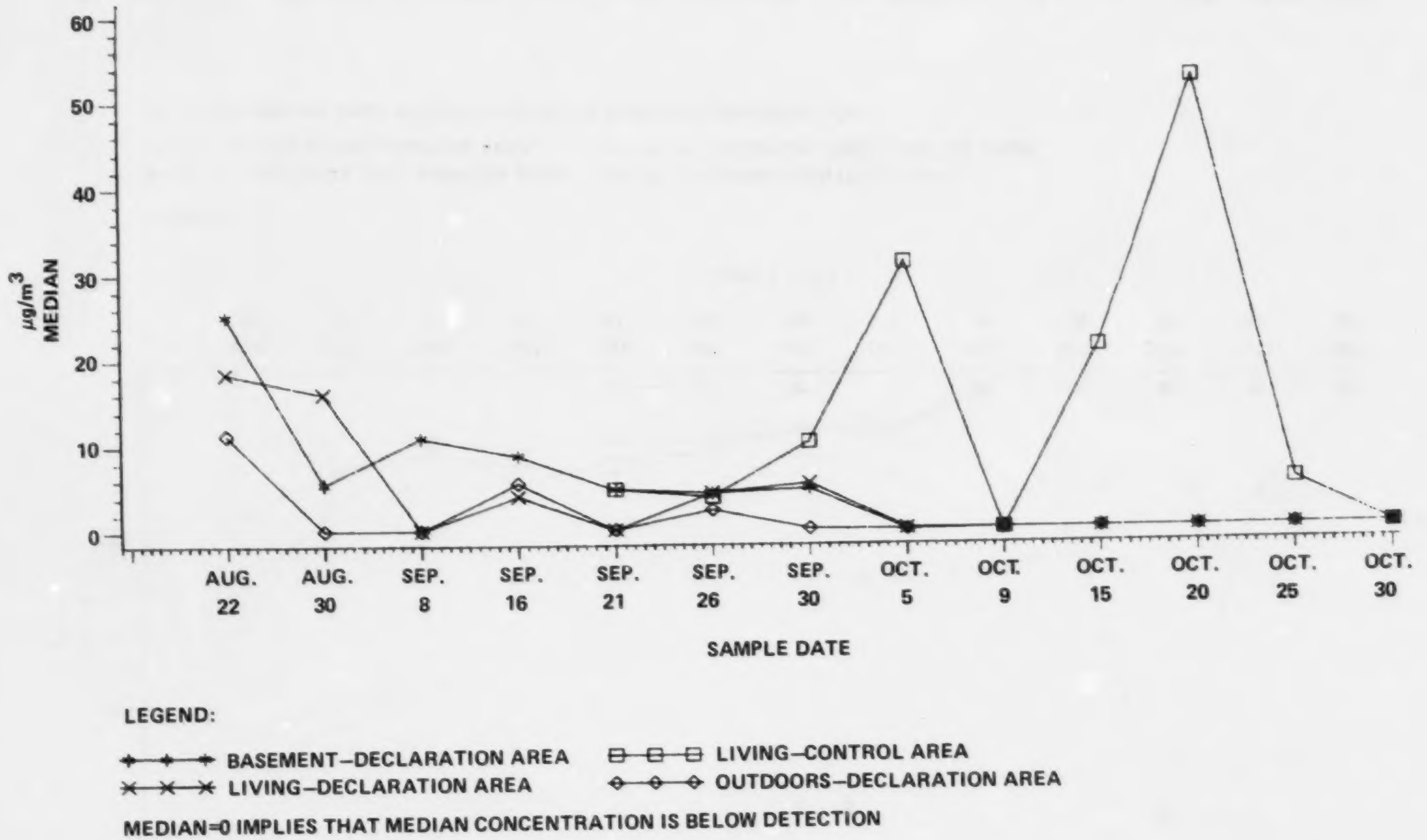


Figure 58. Median Concentration of Toluene Observed in Air for Each Sampling Campaign (micrograms per cubic meter).

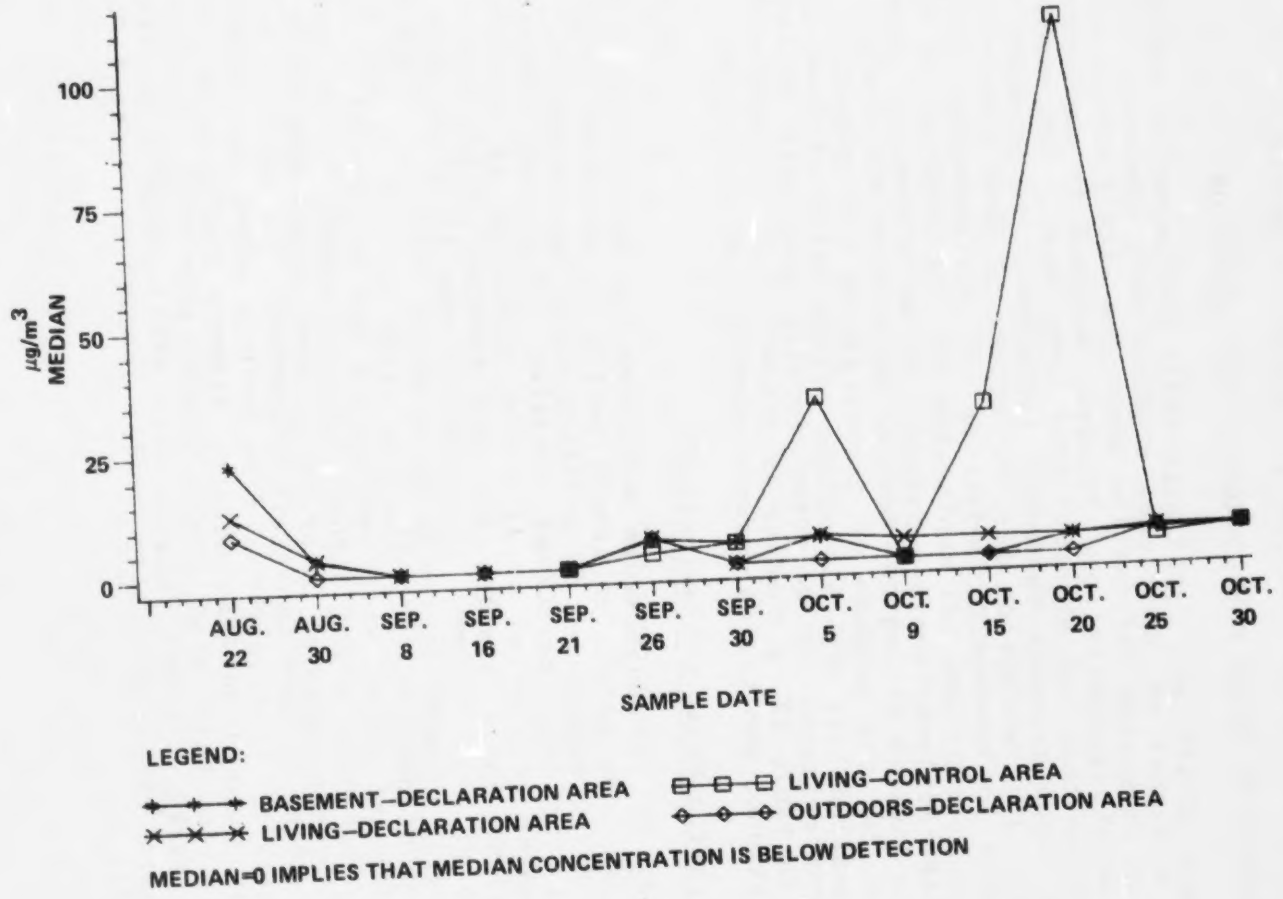


Figure 59. Median Concentration of 1,1,2,2-Tetrachloroethylene Observed in Air for Each Sampling Campaign (micrograms per cubic meter).

contaminated sumps (which were found in only a limited number of ring 1 residences) could serve as potential contributing sources of high levels of indoor air pollution. And third, activities associated with domiciliary occupancy suggested that such activities could potentially increase air pollution levels.

4.3 EVIDENCE OF OTHER ENVIRONMENTAL CONTAMINATION

As part of the Love Canal multimedia environmental monitoring program, a number of additional studies were conducted for the purpose of obtaining information about the likely extent and degree to which residents were directly exposed to environmental contamination that had migrated from Love Canal. The studies of potential human exposure conducted included: (1) drinking water monitoring; (2) monitoring for the uptake of Love Canal-related contaminants in household foodstuff; (3) environmental radioactivity monitoring; and (4) monitoring for the presence of dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin) in environmental samples. Finally, a limited biological monitoring program was conducted at Love Canal for the purpose of investigating the potential biological availability and biological accumulation of Love Canal-related contaminants in selected locally available biological species. In Table 12, a summary is presented of the magnitude of these additional monitoring efforts conducted at Love Canal.

4.3.1 Drinking Water Contamination

As part of the multimedia environmental monitoring program conducted at Love Canal, an investigation of potential human exposure to toxic substances in drinking water was performed. The monitoring that was performed entailed collecting samples of drinking water at a total of 44 sites, involving 42 residences, and analyzing those samples for the substances identified in Appendix A of this Volume. Included in the 44 sites were two separate sites located in the Drinking Water Treatment Plant of the City of Niagara Falls. The two sites located in the plant (sites 97013 and 97014) were sampled for the purpose of monitoring raw (untreated) and finished drinking water, respectively. In Figure 60, the location of drinking water sites sampled in the general vicinity of Love Canal are presented. In addition to the sites identified in Figure 60, five control sites were sampled: site 99010, located on 82nd Street, Niagara Falls; site 99020, located on Stony Point Road, Grand Island; site 99021, located on West River Parkway, Grand Island; site 99022, located on Pierce Road, Niagara Falls; and site 99023, located on Packard Road, Niagara Falls.

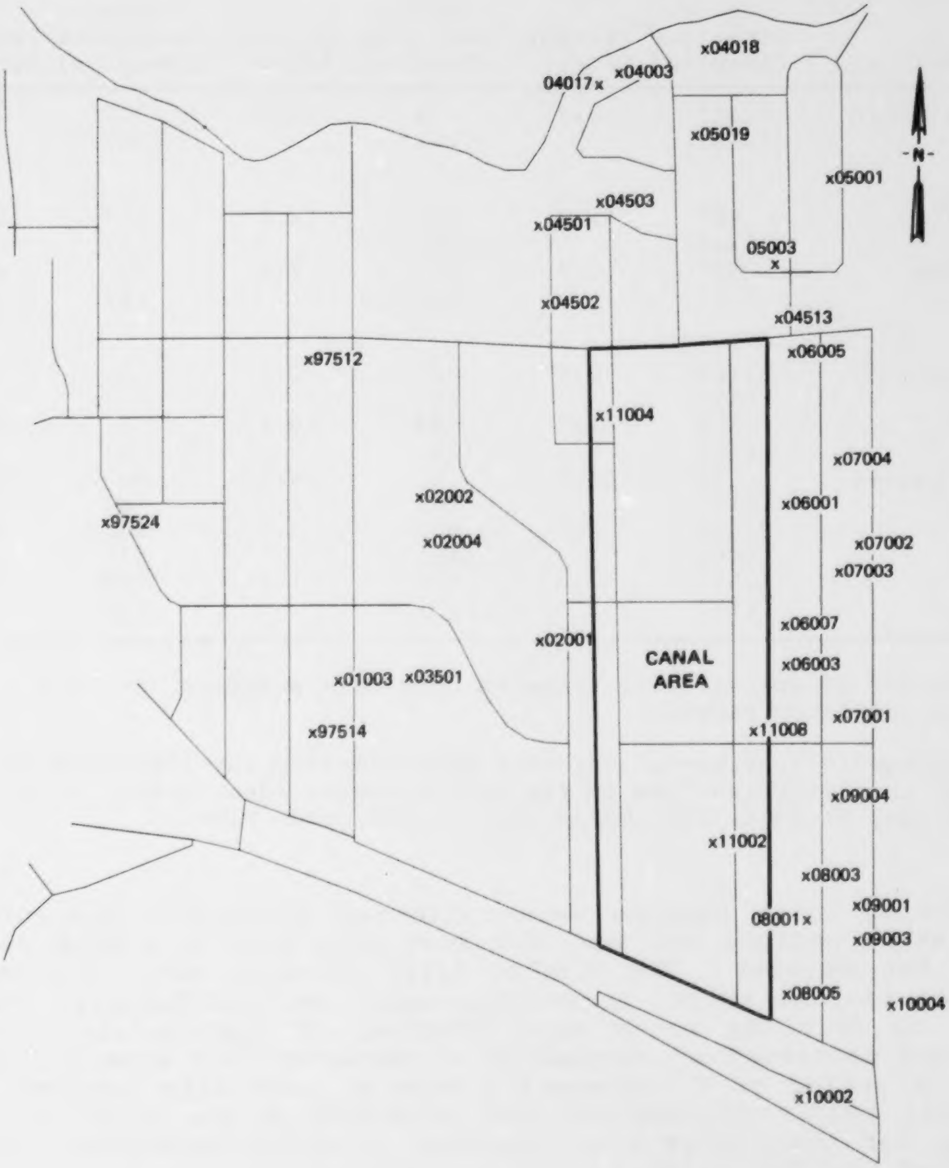

x04018
04017x
x04003
x05019
x05001
N
x04503
x04501
05003
x
x04502
x04513
x06005
x97512
x11004
x07004
x02002
x06001
x97524
x02004
x07002
x07003
x06007
x02001
CANAL
AREA
x06003
x01003
x03501
x07001
x11008
x97514
x09004
x11002
x08003
x09001
08001x
x09003
x08005
x10004
x10002

Figure 60. Drinking Water Sampling Site Codes.

TABLE 12. FREQUENCY OF DETECTION OF CONTAMINANTS IN ADDITIONAL VALIDATED LOVE CANAL SAMPLES

	Declaration Area		Control		Canal Area	
Medium/Source	Determinations[†] (Samples)	Percent Detect	Determinations (Samples)	Percent Detect	Determinations (Samples)	Percent Detect
Drinking Water	4,403 (173)	8.3	674 (26)	12.9	710 (25)	7.6
Foodstuff						
Oatmeal	507 (13)	11.2	156 (4)	12.2	117 (3)	10.3
Potatoes	468 (12)	3.4	117 (3)	3.4	78 (2)	4.0
Biota						
Crayfish	3,169 (31)	0.9	880 (9)	2.2	0 (0)	--
Dogs	308 (23)	62.7	244 (18)	64.8	0 (0)	--
Maple Leaves	150 (15)	66.0	140 (14)	64.3	80 (8)	68.8
Mice	3,604 (48)	4.1	3,601 (45)	3.6	553 (7)	4.2
Worms	1,573 (19)	2.3	616 (5)	1.3	528 (6)	0.9

[†] Total number of specifically targeted chemicals analyzed for in all combined validated samples

Note: Inorganic substances represent approximately the following percent of the determinations in the medium/source identified: drinking water, 9; dogs, 100; maple leaves, 100; and, mice, 4.

Drinking water samples were collected throughout the course of the study period, but were obtained only once from each residential tap sampled. The Niagara Falls Drinking Water Treatment Plant was sampled twice, in mid-September and mid-October, 1980. Samples of drinking water were obtained by appropriate procedures, and consisted of composites of tapwater that were collected over a period of 4 consecutive days at each site sampled; an additional sample of tapwater was collected on the first day of sampling for the analysis of targeted volatile compounds. Criteria used for the selection of residential drinking water sampling sites included: (1) sampling at base residences as part of the multimedia monitoring program; (2) sampling residences in the Declaration and Canal Areas served by each distribution main; and (3) randomly (with equal probability) selecting residences for sampling. In addition, a number of residential taps were sampled at the request of local residents.

The findings of the drinking water monitoring program may be stated concisely. First, no evidence was found (at the limits of detection employed in this study) that the drinking water samples analyzed were directly contaminated by the infiltration of contaminants from Love Canal into the water distribution mains sampled. Second, organic compounds primarily detected in the drinking water were trihalomethanes, which are typically formed in drinking water as a result of the bacteria-killing chlorination treatment process. The concentration levels of the trihalomethanes found in the drinking water were less than, or comparable to, the levels commonly reported elsewhere. (See Appendix B of this Volume). Third, the concentration levels of substances detected in drinking water samples satisfied the existing EPA National Interim Primary Drinking Water Regulations, and the Recommended National Secondary Drinking Water Regulations. (See Table B-11 in Appendix B of this Volume). In comparing the obtained drinking water concentration levels of the results presented in Appendix B, note that 1 part per billion (ppb) equals 0.001 part per million (ppm). Finally, the observed variability in concentration levels of substances detected in drinking water samples could not be distinguished from either measurement error variation or from the day-to-day variation in finished water quality normally observed at treatment plants.

In Figure 61, one typical example of the findings obtained from the drinking water monitoring program is presented. The compound presented in Figure 61 is the trihalomethane, chloroform. As can be seen, no pattern of drinking water contamination was found in the Declaration Area. Additional figures are included in Volume III.

4.3.2 Food Contamination

One of the supplementary, limited monitoring studies conducted at Love Canal involved the purposeful introduction of foodstuff into a select number of air monitoring residences. The objective of this investigation was to determine whether or not the foods introduced accumulated airborne contaminants that were present in the residence by virtue of direct migration from the former canal. It was suspected that if accumulation was found to occur, then residents might also be subjected to incremental chemical insult (assuming sufficient accumulation occurred) from the ingestion of such foods.

The items selected for introduction to a limited number of residences were oatmeal and (not locally grown) potatoes. These foods were chosen due to their common usage and because they were thought to be relatively efficient accumulators of airborne contaminants. Quantities of these foods were acquired and introduced to the basements of certain air monitoring residences for a period of approximately 30 days, and analyzed subsequently for

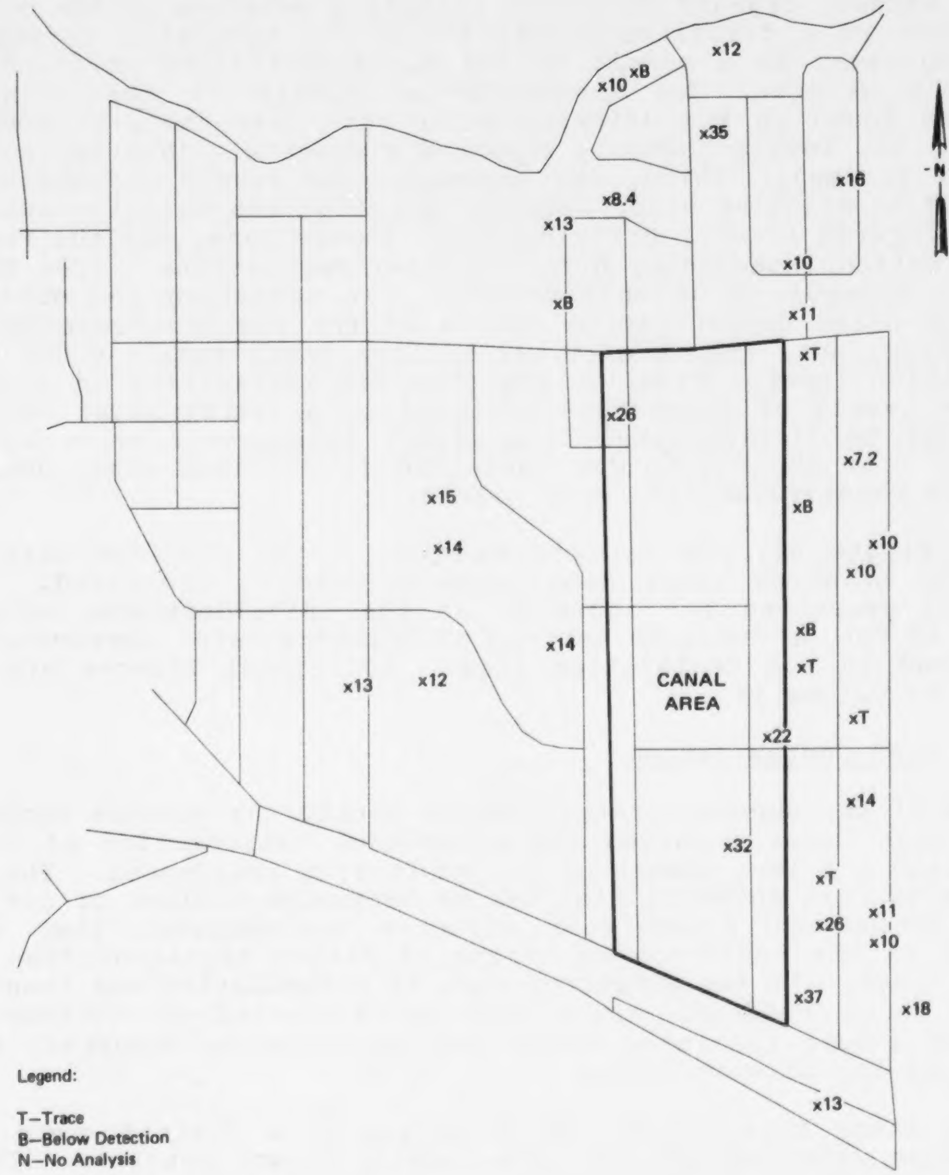

x12
x10
xB
x35
x16
N
x8.4
x13
x10
xB
x11
xT
x26
x7.2
x15
xB
x14
x10
x10
xB
x14
xT
CANAL AREA
x13
x12
xT
x22
x14
x32
xT
x11
x26
x10
x37
x18
x13
Legend:
T—Trace
B—Below Detection
N—No Analysis

Figure 61. Drinking Water Sampling Sites, Chloroform, Maximum Concentrations (micrograms per liter, ppb).

the volatile compounds listed in Table A-1 of Appendix A to this Volume. Those sites in the general Love Canal area in which samples of oatmeal and potatoes were stored are identified (where possible) in Figure 62.

In addition to the sites identified in Figure 62, the following control sites were sampled (site locations were previously identified): sites 99020, 99022, and 99023 for both oatmeal and potatoes; and site 99021 for oatmeal only. A total of 18 sites were used for oatmeal monitoring and 16 sites were used for potato monitoring. Those residences in which samples of oatmeal and potatoes were introduced included base residences and other randomly selected air monitoring sites.

The results obtained from the analysis of oatmeal and potato samples suggested that these foods may potentially accumulate airborne contaminants. It should be noted, however, that the few compounds which were detected in food samples analyzed after storage were present typically at very low trace concentrations (although they were not detected in one sample analyzed prior to storage). The degree to which these findings represent false-positive determinations is not known. Details on the compounds found in foodstuff field samples may be found in Volumes II and III.

The following points should be considered when attempting to interpret the meaning of the results obtained from the oatmeal and potatoes monitoring program. First, only a few of the compounds monitored were uniquely detected after storage. Second, those compounds uniquely detected after storage were typically observed at very low trace concentrations. Third, because no air contamination was found that could be directly attributed to contaminants migrating from the former canal, no significance can be attached to the results of the oatmeal and potatoes monitoring program findings. And finally, because no samples were stored for an identical length of time in a controlled, contaminant-free environment and then subsequently analyzed, no attribution of the source of observed compounds found in stored field samples can be unequivocally made.

4.3.3 Radioactive Contamination

The multimedia environmental monitoring program also included an extensive investigation of the potential presence of radioactive contamination in the general Love Canal area. In order to characterize the extent and degree of radionuclides present in the environment, many of the same sites sampled for water, soil, and sediment were sampled simultaneously for the determination of radioactive contaminants. The following numbers of sites were sampled to determine the radionuclides present: 106 soil sampling sites; 36 sump water sampling sites; the one sanitary sewer sampling site; 20 storm sewer water and 11 storm sewer sediment sampling sites; 2 surface water and 2 stream sediment sampling

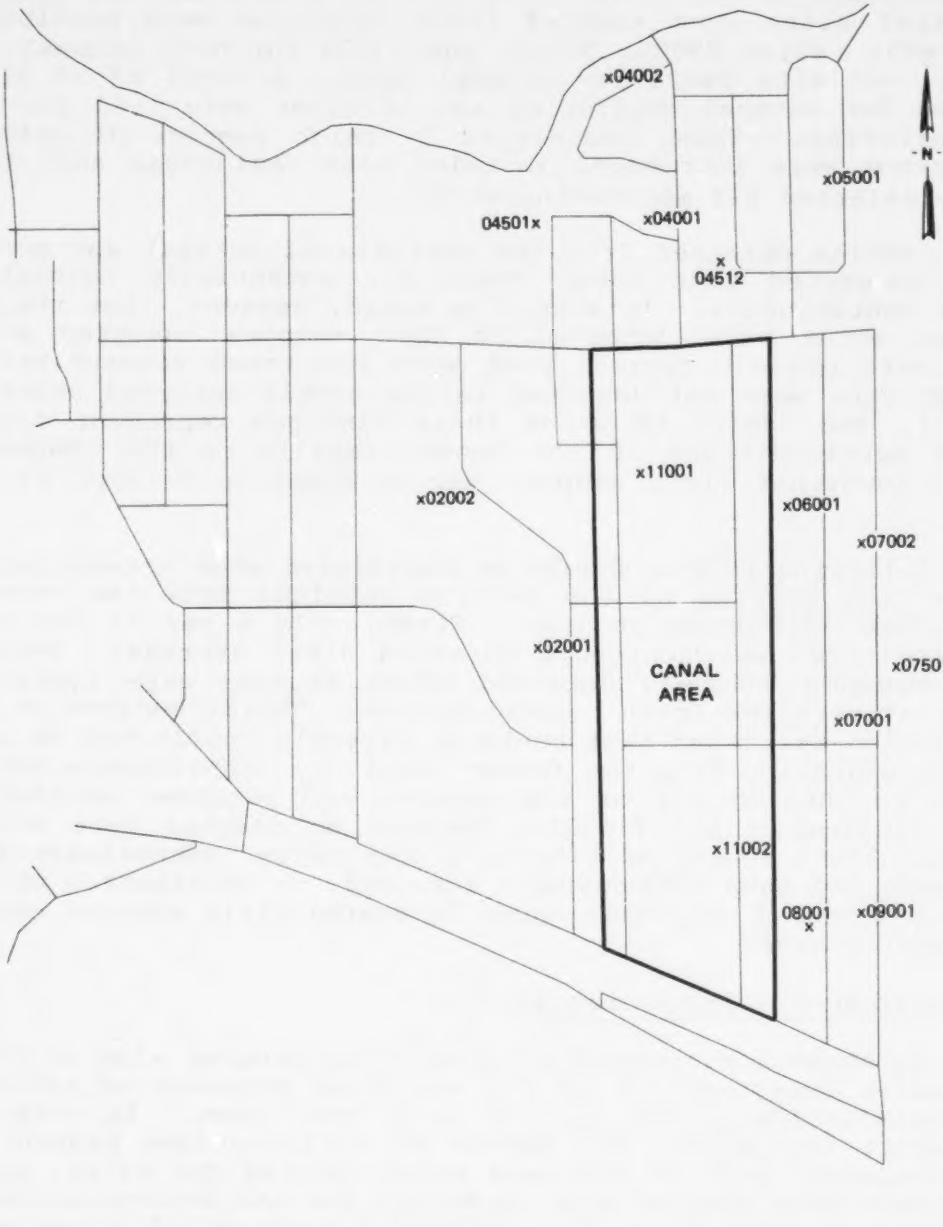

x04002
N
x05001
04501x
x04001
x
04512
x11001
x02002
x06001
x07002
x02001
CANAL
AREA
x07501
x07001
x11002
08001
x
x09001

Figure 62. Oatmeal and Potatoes Sampling Site Codes.

sites; and 10 drinking water sampling sites. Due to the large percentage of sites sampled in each of the medium/source/location categories identified, and because all sampling sites were identified in previous figures, no additional site-specific figures showing the locations sampled for radioactive contaminants are presented.

All samples collected for the determination of radioactive contamination were analyzed for gamma-emitting radionuclides by high resolution gamma spectroscopy. The particular system employed allowed for the detection of all gamma-emitting radionuclides present in a sample in quantities significantly above background levels. In Table 13 the minimum detection levels (based on a 350-gram sample counted for 30 minutes and the average efficiency of the detectors used) are reported for those gamma-emitting radionuclides detected in Love Canal samples.

Drinking water samples were also analyzed for tritium (the radioactive form of hydrogen), in addition to the analysis for gamma-emitting radionuclides. The standard method for tritium analysis, liquid scintillation counting of beta emissions, was employed. The minimum detection level of tritium in drinking water, corresponding to this method, was approximately 300 picocuries per liter (300 pCi/liter). The EPA drinking water standard for tritium is 20,000 pCi/liter.

TABLE 13. MINIMUM DETECTION LEVELS FOR PARTICULAR GAMMA-EMITTING RADIONUCLIDES

Radionuclide	Water Samples	Soil/Sediment Samples
Potassium[†]	2.2 grams per liter	0.0019 grams per gram
Radium-226	50 picocuries per liter	0.04 picocuries per gram
Radium-228	200 picocuries per liter	0.2 picocuries per gram

[†] Approximately 0.0118 percent of all natural potassium consists of the radioactive isotope potassium-40.

Note: No americium-241 was detected in any samples analyzed. Because of the concerns expressed by some residents about its potential presence, its minimum detection level is reported here: in water, 280 picocuries per liter; and in soil/sediment, 0.025 picocuries per gram.

In general, the results obtained from monitoring for environmental radioactive contamination in the Declaration and Canal Areas revealed no evidence of radioactive contamination present at, or having migrated from, Love Canal. Those radionuclides found in soil consisted of the naturally occurring potassium-40 and the (so-called) daughter products of the radium-226 and the thorium-232 decay chains. Three soil samples were also found to contain low levels of cesium-137, comparable in concentration to the levels of cesium-137 attributed to worldwide fallout. Radioanalyses of all water samples collected, including drinking water, revealed that no gamma-emitting radionuclides were present above background levels. Analyses of the drinking water samples for tritium yielded a maximum concentration of approximately 1,800 picocuries per liter, a value well below the current EPA drinking water maximum contaminant level (20,000 pCi per liter).

Storm sewer sediment samples collected from the Canal Area were found to contain low levels of potassium-40, corresponding to 5 to 8 milligrams of total potassium per gram of sediment. All Canal Area storm sewer sediment samples also contained low levels of cesium-137 (0.014 to 0.79 pCi per gram). These levels are consistent with values found in other parts of the country, and are attributable to worldwide fallout. Radium-226 in storm sewer sediment from the Canal Area varied in concentration from 0.39 to 0.94 pCi per gram. All of the storm sewer sediment samples from the Canal Area contained daughter products of thorium-232. Assuming equilibrium of the daughter products with the thorium-232, the concentration ranged from 0.23 to 0.36 pCi of thorium-232 per gram of sediment.

Storm sewer sediment samples collected in the Declaration Area contained from 2 to 27 milligrams of potassium per gram of sediment. A total of 24 samples were found to contain cesium-137 at concentrations ranging from 0.084 to 0.97 pCi per gram, comparable once again to worldwide fallout levels. Radium-226 in storm sewer sediment samples from the Declaration Area varied in concentration from 0.20 to 6.6 pCi per gram; only three of the samples had concentrations of radium-226 greater than 1 pCi per gram (1.6, 2.2, and 6.6 pCi per gram). In addition, a number of storm sewer sediment samples from the Declaration Area contained the daughter products of thorium-232, at levels that indicated a thorium-232 concentration ranging from 0.22 to 1.9 pCi of thorium-232 per gram of sediment.

Finally, stream sediment samples collected from the Declaration Area were found to contain only trace quantities of naturally occurring potassium-40. Samples of stream sediment collected from a control site revealed similar concentrations of potassium-40, and also contained low levels of radium-226 (0.3 pCi per gram) and thorium-232 (0.1 pCi per gram).

4.3.4 Biological Monitoring of Contaminants

A limited program of biological monitoring, involving selected native biological species, was conducted for the purpose of investigating the potential biological availability and biological accumulation of contaminants that may have migrated from Love Canal. It should be made clear that the biological monitoring program was neither designed nor intended to provide insight into the health or ecological effects of those contaminants that might be found in biota. Furthermore, the monitoring program was not intended, and made no attempt, to determine the behavior of any chemicals found in the biological species investigated, to determine the kinetics of biological uptake, or to determine the impact of the chemicals monitored on the species considered. Rather, the biological monitoring program was intended to provide limited, suggestive indication of the accumulation of contaminants in biological systems, thereby potentially increasing the sensitivity of the entire monitoring program to the presence of environmental contaminants that may have migrated from the former canal.

The local species selected for monitoring purposes were crayfish (*Orconectes propinquis*), domestic dogs (*Canis familiaris*), field mice (*Microtus pennsylvanicus*), silver maple tree leaves (*Acer saccharinum*), and worms (*Lumbricus* sp.). In Table 14, the scope of the biological monitoring program is presented. In Figure 63 the locations of biota sampling sites in the Declaration and Canal Areas are presented.

The procedures used to collect samples of the biological species monitored were as follows. Crayfish were obtained by seining approximately 100 meters of Black Creek and Bergholtz Creek, in the general vicinity of local storm sewer outfalls.

TABLE 14. SCOPE OF THE BIOLOGICAL MONITORING PROGRAM

Specy	Sample	Number of Samples (Number of Sites)			Targeted Substances Monitored
		Declaration	Control	Canal	
Crayfish	10 grams composite; whole body	31 (1)	9 (1)	-- --	Organics
Dogs	2 grams of neck hair	23 (20)	18 (15)	-- --	Inorganics
Mice	whole carcass	36 (5)	33 (2)	5 (2)	Organics
Mice	body hair	12 (5)	12 (2)	2 (2)	Inorganics
Silver Maple	10 grams composite; leaves	15 (14)	14 (11)	8 (6)	Inorganics
Worms	10 grams composite; whole body	19 (4)	5 (3)	6 (2)	Organics

Note: Targeted substances monitored are identified in Table A-1 of Appendix A in this Volume. Dashes signify not applicable.

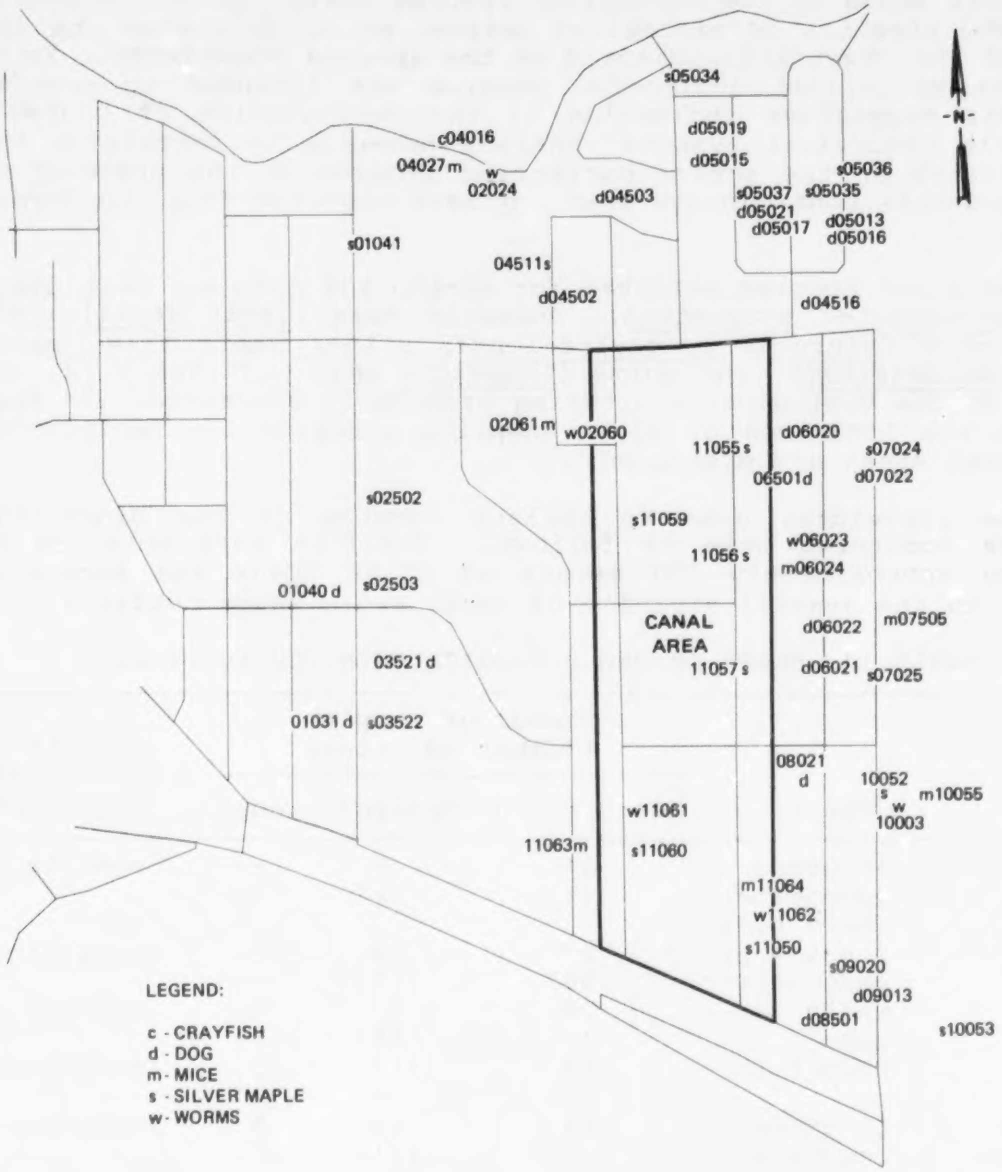

-N-
s05034
d05019
c04016
04027 m
w
02024
d05015
s05036
s05037
s05035
d04503
d05021
d05017
d05013
d05016
s01041
04511 s
d04502
d04516
02061 m
w02060
d06020
11055 s
s07024
06501 d
d07022
s02502
s11059
w06023
11056 s
m06024
01040 d
s02503
CANAL
AREA
d06022
m07505
03521 d
11057 s
d06021
s07025
01031 d
s03522
08021
d
10052
s
w
10003
m10055
w11061
11063 m
s11060
m11064
w11062
s11050
s09020
d09013
d08501
s10053
LEGEND:
c - CRAYFISH
d - DOG
m - MICE
s - SILVER MAPLE
w - WORMS

Figure 63. Biota Sampling Site Codes.

Crayfish were obtained similarly from the control site 99035, located north of Niagara University in Fish Creek. Subsequent to capture, the crayfish were stored in a holding tank (filled with the local creek water from which they were taken) for a fasting period of 48 hours, in order to allow purging of the digestive tract. After the holding period expired, the whole bodies of two or three crayfish were homogenized to form a composite sample of approximately 10 grams, which was necessary for analysis purposes.

Samples of dog hair were obtained from mature domestic dogs (household pets), that were raised in the Declaration Area and provided voluntarily by local residents. Approximately 2 grams of hair were taken from each dog by clipping along the side of the neck.

Field mice were captured by means of live traps placed at the locations indicated in Figure 63, and at control sites 99035 (located north of Niagara University along Fish Creek) and 99071 (located near the intersection of 66th Street and Frontier Avenue in Niagara Falls). Shortly after capture, the obtained specimens were sacrificed by cervical dislocation. Samples of hair were obtained by shaving each mouse of all body hair, and forming composites of body hair from three mice captured in the same general location. After shaving, each mouse was skinned and the legs and tail were removed. The carcass was then eviscerated and the remainder homogenized to form a sample that was submitted for analysis.

The leaves from silver maple trees were collected in the general area of the sites identified in Figure 63 and at control sites. Samples were formed by compositing 10 outer leaves from each of 10 silver maple trees located at each site. Composite samples that were formed consisted of at least 10 grams of dry leaves.

Finally, worms were collected from the sites identified in Figure 63 and from the control sites 99008 (located on Frontier Avenue, Niagara Falls), 99020 (located on Stony Point Road, Grand Island), and 99021 (located on West River Parkway, Grand Island). Prior to sampling, each site was watered (if necessary) in order to saturate the surface soil. One-meter square plots were then dug to a depth of 15 centimeters and the unearthed worms were collected. After collection, the worms were placed in moist cornmeal for 24 hours to allow purging of the digestive tract. Next, 10-gram composite samples of worms obtained from each plot were homogenized prior to analysis.

The results from the biological monitoring program were found to be of limited value. Because the results obtained did not demonstrate the biological uptake of contaminants from the former canal (that is, the findings conformed with the results of the environmental monitoring program), they will not be discussed in detail here. The interested reader is instead referred to Volumes II and III of this report for more specific information.

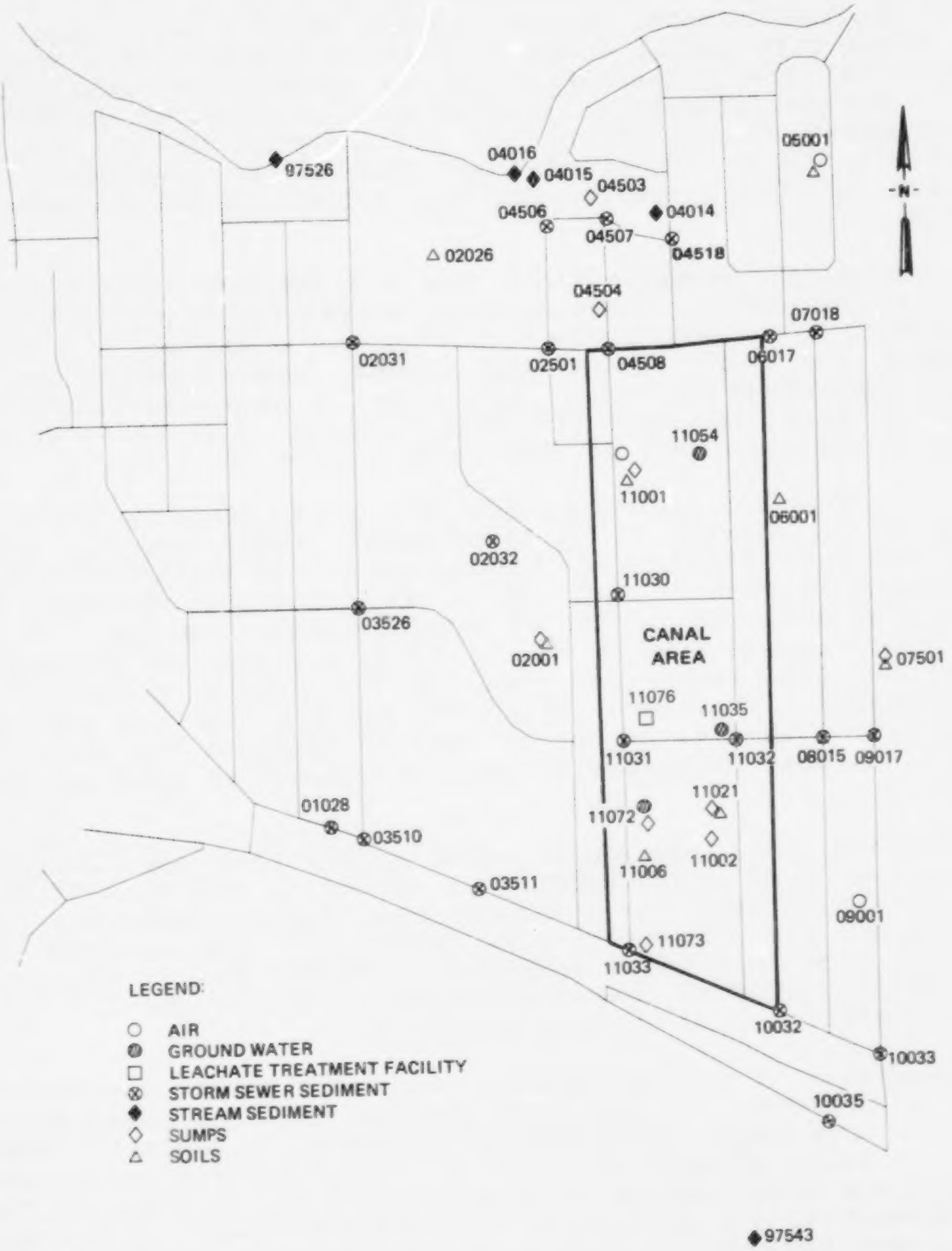
4.3.5 Dioxin (2,3,7,8-TCDD)

By intent, the results of specific monitoring for tetrachlorinated dibenzo-p-dioxins (TCDDs), particularly the 2,3,7,8-TCDD isomer, in environmental samples collected in the vicinity of Love Canal were reserved for unified presentation. The motivation for a separate discussion of the sampling, analytical, and quality assurance procedures and results for TCDDs analyses stemmed, in part, from the high toxicity of the 2,3,7,8-TCDD isomer and, in part, from the expressed concerns of local residents regarding potential sources of human exposure.

As part of the multimedia environmental monitoring program conducted at Love Canal, a number of samples were analyzed by high resolution gas chromatography/high resolution mass spectrometry (HRGC/HRMS) for the determination of 2,3,7,8-TCDD. In Figure 64, the locations of sites monitored for 2,3,7,8-TCDD are given, and are identified by medium and source. As with many other environmental samples collected at Love Canal, the selection of 2,3,7,8-TCDD monitoring sites was directed intentionally towards known or suspected transport pathways. For example, the limited results from previous investigations of TCDDs at Love Canal by NYS were used partially to aid in the selection of 2,3,7,8-TCDD sampling sites.

All samples collected for the determination of 2,3,7,8-TCDD were analyzed by Wright State University (WSU) under the direction of the EPA Health Effects Research Laboratory, Research Triangle Park, North Carolina (HERL-RTP). Air samples were collected on polyurethane foam plugs and were extracted with benzene. Water, soil, and sediment samples were collected as described previously and were extracted using petroleum ether and agitation. Primary extracts were subjected, as necessary, to extensive additional purification prior to analysis. The labeled internal standard $^{37}Cl_4$-2,3,7,8-TCDD was added to all samples before primary extraction. Additional details concerning the analytical methods used for 2,3,7,8-TCDD determinations may be found in G. F. Van Ness, et al., Chemosphere, Vol. 9 (1980), 553-563, and R. L. Harless, et al., Analytical Chemistry, Vol. 52, No. 8 (1980), 1239-1245.

The limit of detection for the methodology was ordinarily in the range of 1 to 20 nanograms per kilogram or nanograms per liter (parts per trillion -- ppt), and varied according to sample medium and sample source. For example, samples containing a relatively high organic content (such as aquatic sediment samples) had an associated limit of detection near the upper end of the range, while samples free of organic interferences had a limit of detection near the lower end of the range.



N
97526
04016
04015
04503
04506
04507
04014
04518
05001
02026
04504
07018
02031
02501
04508
06017
11054
11001
06001
02032
11030
03526
CANAL
AREA
02001
07501
11076
11035
11031
11032
08015
09017
01028
03510
11021
11072
11006
11002
03511
09001
11073
11033
10032
10033
10035
97543
LEGEND:
○ AIR
● GROUND WATER
□ LEACHATE TREATMENT FACILITY
⊗ STORM SEWER SEDIMENT
◆ STREAM SEDIMENT
◇ SUMPS
△ SOILS

Figure 64. Sampling Site Codes for Dioxin (2,3,7,8-TCDD).

Analytical performance of WSU was evaluated regularly during the Love Canal project. Performance evaluation samples were prepared by HERL-RTP by adding known amounts of 2,3,7,8-TCDD to specially obtained samples of soil. These samples were submitted to WSU, along with actual Love Canal field samples, in a manner that precluded their identification as performance evaluation samples. The performance evaluation samples prepared contained either no added analyte, 60 ppt of 2,3,7,8-TCDD, or 120 ppt of 2,3,7,8-TCDD. On the basis of these samples the performance of WSU for 2,3,7,8-TCDD determinations was judged, in all instances, acceptable.

All analytical determinations for 2,3,7,8-TCDD by WSU were validated by HERL-RTP. Every extract containing a positive determination of TCDDs was divided by WSU, and a portion was sent to HERL-RTP for confirmation and isomer identification on a different HRGC/HRMS system. All postive determinations of 2,3,7,8-TCDD were validated in this fashion, and all samples collected for the analysis of TCDDs were validated.

The recovery 2,3,7,8-TCDD from the performance evaluation soil samples varied from 32 to 77 percent. These results, however, are not considered valid indicators of the accuracy of the soil and sediment methodology. As is pointed out in Appendix D, in the section entitled "Limits of Detection/Quantitation," it is very difficult to add a known amount of an analyte (or analytes) to a soil/sediment sample and simulate the natural sorption or uptake processes. Therefore, while the results from the performance evaluation samples cannot be used to estimate the accuracy of the method, they do generally confirm the method limit of detection.

In addition, one Love Canal water sample that contained no detectable amount of 2,3,7,8-TCDD was spiked by WSU with 91 ppt of 2,3,7,8-TCDD. This water sample was sent to HERL-RTP (in blind fashion) for extraction and analysis. The recovery of 2,3,7,8-TCDD from this water sample by HERL-RTP was 71 percent, which is an indicator of the accuracy of the method for 2,3,7,8-TCDD determinations in water samples.

The precision of the methodology for 2,3,7,8-TCDD determinations is indicated by the positive results from the measurement of duplicate Love Canal field samples presented in Table 15. When expressed in terms of percent relative range (the difference between duplicate measurements as a percentage of the mean of the two measurements), the precision of the method was 5.2 percent and 26 percent for the two duplicates with hundreds of parts per billion concentrations, and 87 percent for the one duplicate with parts per trillion concentrations.

The results obtained from the special 2,3,7,8-TCDD monitoring program were as follows. The presence of 2,3,7,8-TCDD in Love

TABLE 15. RESULTS OF STORM SEWER SEDIMENT DETERMINATIONS FOR 2,3,7,8-TCDD (micrograms per kilogram)

Site	Location	2,3,7,8-TCDD Concentration (ppb)
11030	97th Street and Read Avenue	329
04508	97th Street and Colvin Boulevard[†]	672 and 638[‡]
02501	96th Street and Colvin Boulevard[†]	5.39
04506	96th Street and Greenwald Avenue[†]	170
04507	97th Street and Greenwald Avenue	B
02032	96th Street, near Apt. 620 in Court 2	B
11031	97th Street and Wheatfield Avenue[†]	199
11033	97th Street and Frontier Avenue[†]	393 and 303[‡]
10032	100th Street and Frontier Avenue[†]	0.2 and B[‡]
10033	102nd Street and Frontier Avenue[†]	B and B[‡]
10035	Buffalo Avenue near 10108 Buffalo[†]	B
11032	99th Street and Wheatfield Avenue[†]	0.2
08015	101st Street and Wheatfield Avenue[†]	0.4
09017	102nd Street and Wheatfield Avenue[†]	B
06017	100th Street and Colvin Boulevard[†]	0.054
07018	101st Street and Colvin Boulevard[†]	B
03511	Frontier Avenue between 93rd and 96th Streets	B and B[‡]
03510	93rd Street and Frontier Avenue	B
01028	Frontier Avenue between 92nd and 93rd Streets	B and B[‡]
03526	93rd Street and Read Avenue	B
02031	93rd Street and Colvin Boulevard	0.165 and 0.419[‡]

[†] Storm sewer line turning point or junction
[‡] Duplicate analyses performed

B: Below detection

Note: As best as possible, storm sewer sites are organized by sewer line and presented according to sequential waterflow direction originating at those sites located closest to the midpoint of Love Canal. (See Figure 12).

Canal was determined from the analysis of two leachate samples collected in the Leachate Treatment Facility (site 11076). The results of the analyses conducted on the solution phase samples of leachate revealed a concentration of 1.56 micrograms per liter (ppb) in the untreated influent sample, and below detection level results (approximately 5 to 10 nanograms per liter) for the treated effluent sample.

The presence of 2,3,7,8-TCDD was not detected in any of the ground-water samples analyzed. And, no 2,3,7,8-TCDD was detected in any of the soil samples analyzed. Note, however, that no soil samples were collected directly in the known sand lens on the western side of Love Canal, where 2,3,7,8-TCDD had been found previously by NYS DOH.

The only sumps found to contain measurable amounts of 2,3,7,8-TCDD were located in ring 1 residences in the Canal Area. The sumps found to contain 2,3,7,8-TCDD were also noted previously as containing high levels of contamination, with numerous other organic compounds present. In particular, the sump sediment sample collected from site 11072 (located at 771 97th Street), a residence identified previously as collinear with the known sand lens on the western side of Love Canal, had a high concentration of 9,570 ppb of 2,3,7,8-TCDD present. In addition, the two sumps located in the residence at site 11021 (476 99th Street) had 2,3,7,8-TCDD present at concentrations of 0.5 ppb and 0.6 ppb. The sample of sump sediment obtained from site 11073 (703 97th Street) contained no measurable amount of 2,3,7,8-TCDD.

The presence of 2,3,7,8-TCDD was detected in a number of storm sewer sediment samples collected from throughout the general Love Canal area. The results obtained are summarized in Table 15. Note that in Table 15 an attempt was made to group sampling sites by storm sewer line, and to list sites by waterflow direction starting at Love Canal. As can be seen from the results presented in Table 15, decreasing concentrations of 2,3,7,8-TCDD were found in certain storm sewer lines as distance from the former canal increased. In particular, starting with the storm sewer turning points on 97th Street and on 99th Street, decreasing concentrations of 2,3,7,8-TCDD were found in the storm sewer lines heading in the direction of the 96th Street outfall, the outfall in Black Creek between 101st and 102nd Streets, and the 102nd Street outfall. (See Figure 12).

These findings strongly suggest that the transport of sediment by waterflow served as the likely mechanism of 2,3,7,8-TCDD movement through the storm sewer lines sampled. The fact that 2,3,7,8-TCDD has very low solubility in water and very high sorption properties on sediment, tends to support this hypothesis.

The stream sediment samples analyzed for 2,3,7,8-TCDD revealed that 2,3,7,8-TCDD had likely been transported through the storm sewer lines into the creeks and river sampled. At site 04014, located in Black Creek near 98th Street, 0.075 ppb of 2,3,7,8-TCDD was detected. Further west in Black Creek, at site 04015, located near the storm sewer outfall, 37.4 ppb of 2,3,7,8-TCDD was detected. While at site 04016, located in Bergholtz Creek near its junction with Black Creek, 1.32 ppb of 2,3,7,8-TCDD was found. Further downstream in Bergholtz Creek at site 97526, located west of 93rd Street, the presence of 2,3,7,8-TCDD was not detected. Also sampled was site 97543, located in the Niagara River near the 102nd Street storm sewer outfall. Sediment from this site was analyzed in triplicate and yielded concentrations of 0.1, 0.06, and 0.02 ppb of 2,3,7,8-TCDD. Because of the proximity of site 97543 to the 102nd Street landfill, and the failure to detect 2,3,7,8-TCDD in the storm sewer site sampled closest to the outfall (site 10035), the source of the 2,3,7,8-TCDD present in the Niagara River could not be clearly identified.

Finally, no 2,3,7,8-TCDD was detected in any of the air samples analyzed.

To reiterate, it was determined that 2,3,7,8-TCDD was present in the untreated leachate, in the sumps of certain ring 1 residences, in the sediment of storm sewers emanating from near the former canal, and in the sediment of local creeks and the Niagara River sampled in the vicinity of outfalls of storm sewer lines that originated near Love Canal. These results for Love Canal-related 2,3,7,8-TCDD environmental contamination are in conformity with the findings presented earlier, and are also in agreement with the less comprehensive results reported by NYS DOH in 1980.

CHAPTER 5
SUMMARY AND CONCLUSIONS

The EPA multimedia environmental monitoring program conducted at Love Canal provided a substantial amount of information on the extent and degree of environmental contamination in the Declaration Area that resulted directly from the migration of contaminants from the former canal. In general, the monitoring data revealed that except for residual contamination in certain local storm sewer lines and portions of creeks located near the outfalls of those storm sewers, the occurrence and concentration levels of chemicals found in the Declaration Area (in each media monitored) were comparable to those found at nearby control sites. The monitoring data also revealed that contamination that had most likely migrated directly from Love Canal into residential areas was confined to relatively localized portions of ring 1 in the Canal Area (that is, near certain unoccupied houses located adjacent to the former canal). In addition, comparative data from other locations in the United States (presented in Appendix B of this Volume) revealed that the observed occurrence and concentration levels of those chemicals monitored in the residential portions of the Declaration Area and elsewhere were comparable. Furthermore, comparisons of the concentration levels of environmental contaminants found in the residential portions of the Declaration Area with existing EPA standards revealed that no environmental standards were violated.

A review of all of the environmental monitoring data collected at Love Canal also revealed that no evidence was obtained which demonstrated that residential portions of the Declaration Area exhibited measurable environmental contamination that was directly attributable to the presence of contaminants that had migrated from the former canal. In addition, it is unlikely that undetected Love Canal-related contamination exists in the residential portions of the Declaration Area, because the targeted substances monitored and the sampling locations selected for monitoring purposes were intentionally directed (based on the best available evidence) to maximize the probability of detecting contaminants that had migrated from the former canal.

The absence of Love Canal-related environmental contamination in the Declaration Area, other than that which was mentioned previously, conformed with the results and implications of the hydrogeologic investigations conducted in the general Love Canal area. Specifically, the well-defined multimedia pattern of environmental contamination found in shallow system ground-water samples, in soil samples, and in sump samples collected at certain locations in ring 1 of the Canal Area, was in full agreement with (and corroborated) the hydrogeologic program results.

The following points highlight the major findings of the EPA multimedia environmental monitoring program conducted at Love Canal.

- The hydrogeologic program results demonstrated that there is little potential for migration of contaminants from Love Canal into the Declaration Area. These findings conformed fully with the results of the multimedia environmental monitoring program. Furthermore, the close correspondence of the multimedia monitoring data to the implications of the geological and hydrological characteristics of the site minimized the likelihood that potential limitations inherent in the state-of-the-art analytical methods used during the study resulted in artifactual or fallacious conclusions regarding the extent and degree of environmental contamination at Love Canal.

- The results from the hydrogeologic program suggested that the barrier drain system, which was installed around the perimeter of Love Canal in 1978 and 1979, is working as designed. In particular, the outward migration of contaminants through more permeable overburden soil has been contained, and the movement of nearby shallow system ground water is towards the drain. Consequently, contaminated shallow system ground water beyond the barrier drain will be drawn towards Love Canal, intercepted by the barrier drain system, and decontaminated in the Leachate Treatment Facility. Previously reported EPA testing of the effectiveness of the Leachate Treatment Facility demonstrated an operating efficiency of greater than 99 percent removal of all monitored organic compounds in the influent leachate. Discharged liquids from the facility are transported through the sanitary sewer system to the City of Niagara Falls wastewater treatment plant for additional treatment.

- Except for some apparently isolated pockets of shallow system ground-water contamination located immediately adjacent to the former canal, no general pattern of contamination was found in the shallow system. Furthermore, no significant shallow system ground-water contamination attributable directly to migration from Love Canal was found outside of ring 1 in the Canal Area.

- Low level, widespread contamination was observed throughout the bedrock aquifer. However, ground-water samples from the bedrock aquifer located in the Lockport Dolomite did not reveal a pattern of contamination that had migrated directly from Love Canal.

- No Love Canal-related patterns of contamination were found in soil samples collected in the Declaration Area. Patterns of soil contamination attributable to contaminants having migrated from Love Canal were found in ring 1 of the Canal Area, and were associated with known or suspected preferential transport pathways in the soil, and with the occurrence of shallow system ground-water contamination.

- No evidence of Love Canal-related contamination that had migrated preferentially through former swales into the Declaration Area was found, nor were "wet" area residences found to have higher concentrations of contamination than "dry" residences.

- Evidence of residual contamination that had most likely migrated from Love Canal was present in sump samples collected in a few residences located immediately adjacent to the former canal (that is, within ring 1).

- Evidence of residual contamination that had most likely migrated from Love Canal was found in those storm sewer lines which originated near Love Canal in the Canal Area.

- Evidence of residual contamination that had most likely migrated from Love Canal was present in the sediments of certain creeks and rivers sampled near to those storm sewer outfalls of sewer lines originating near the former canal.

- Results from monitoring activities in the residential portions of the Declaration Area revealed that the contamination present was comparable to that at the control sites, to concentrations typically found in the ambient environment, and to concentrations found in other urban locations. In general, no environmental contamination that was directly attributable to the migration of contaminants from Love Canal was found in the Declaration Area (outside of the previously mentioned storm sewer lines and creeks).

Finally, a review of the results from the entire Love Canal environmental monitoring study revealed that: (1) except for contamination present in sediments of certain storm sewers and of certain local surface waters, the extent and degree of environmental contamination in the area encompassed by the emergency declaration order of May 21, 1980 were not attributable to Love Canal; (2) the short-term implications of ground-water contamination are that a continued effective operation of the barrier drain system surrounding Love Canal will contain the lateral migration of contaminants through the overburden, and the long-term implications are that little likelihood exists for distant ground-water transport of contaminants present in the Canal Area; and (3) a review of all of the monitoring data revealed that there was no compelling evidence that the environmental quality of the Declaration Area was significantly different from control sites or other areas throughout the United States for which monitoring data are available.

APPENDIX A
LISTS OF SUBSTANCES MONITORED AT LOVE CANAL

The following two tables contain lists of substances that were routinely determined in samples collected during the EPA Love Canal multimedia environmental monitoring program. Table A-1 contains a list of targeted organic and inorganic substances that were determined in water, soil, sediment, and biological samples. In Table A-2, a list is presented of targeted organic and inorganic substances that were determined in air samples.

TABLE A-1. SUBSTANCES MONITORED IN LOVE CANAL WATER/SOIL/SEDIMENT/BIOTA SAMPLES

Volatiles-Method 624 Analytes
(Medium: Water/Soil/Sediment/Biota)

Methylene chloride
Chloromethane
1,1-Dichloroethene
Bromomethane
1,1-Dichloroethane
Vinyl chloride
cis-1,2-Dichloroethene
Chloroethane
trans-1,2-Dichloroethene
Trichlorofluoromethane
Chloroform
1,2-Dichloroethane
1,2-Dichloroethene
1,1,1-Trichloroethane
Carbon tetrachloride
Bromochloromethane
Bromodichloromethane
2,3-Dichloropropene
1,2-Dichloropropane
Trichloroethene
trans-1,3-Dichloropropene
Benzene
Acrolein
Acrylonitrile
Dibromochloromethane
1,1,2-Trichloroethane
Bromoform
1,1,2,2-Tetrachloroethane
Benzyl chloride
o-Xylene
m-Xylene
p-Xylene
Tetrachloroethene
Toluene
2-Chlorotoluene
3-Chlorotoluene
4-Chlorotoluene
Chlorobenzene
Ethyl benzene
1,2-Dibromoethane

(continued)

TABLE A-1 (continued)

Phenols and Base/Neutrals-Method 625 Analytes
(Medium: Water/Soil/Sediment/Biota)

2-Chlorophenol
3-Chlorophenol
4-Chlorophenol
2-Nitrophenol
Phenol
2,4-Dimethylphenol
2,4-Dichlorophenol
2,3,5-Trichlorophenol
2,4,6-Trichlorophenol
4-Chloro-3-methylphenol
2,4-Dinitrophenol
2-Methyl-4,6-dinitrophenol
Pentachlorophenol
4-Nitrophenol
Hexachloroethane
1,4-Dichlorobenzene
1,3-Dichlorobenzene
1,2-Dichlorobenzene
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
N-nitrosodi-n-propylamine
Hexachlorobutadiene
1,2,3-Trichlorobenzene
N-nitrosodimethylamine
1,2,4-Trichlorobenzene
1,3,5-Trichlorobenzene
Nitrobenzene
Naphthalene
Isophorone
Bis(2-chloroethoxy)methane
Hexachlorocyclopentadiene
  (C-56)
2-Chloronaphthalene
Acenaphthylene
Acenaphthene
Dimethylphthalate
2,6-Dinitrotoluene
Fluorene
1,2-Diphenylhydrazine
4-Chlorophenylphenylether
2,4-Dinitrotoluene
2,4-Dichlorotoluene
Diethylphthalate
N-nitrosodiphenylamine
Hexachlorobenzene
4-Bromophenylphenylether
Phenanthrene
Anthracene
Di-n-butyl phtalate
Fluoranthene
Pyrene
Benzidine
Butylbenzylphthalate
Di(2-ethylhexyl)phthalate
Chrysene
Di-n-octylphthalate
Benzo(a)anthracene
Benzo(k)fluoranthene
Benzo(b)fluoranthene
Benzo(a)pyrene
3,3-Dichlorobenzidine
Indeno(1,2,3-dc)pyrene
Dibenzo(a,h)anthracene
Benzo(g,h,i)perylene
Pentachloronitrobenzene
2,4,6-Trichloroaniline
4-Chlorobenzotrifluoride
(Trifluoro-p-chlorotoluene)
1,2,3,4-Tetrachlorobenzene
1,2,4,5-Tetrachlorobenzene
Tetrachlorotoluenes
  (18 position isomers--ring
  and methyl substitution)

(continued)

TABLE A-1 (continued)

Aroclors (PCBs) and Pesticides-Methods 608 and 625 Analytes
(Medium: Water/Soil/Sediment/Biota)

α-BHC
β-BHC
δ-BHC
γ-BHC (Lindane)
Heptachlor
Aldrin
Mirex
Endosulfan I
Heptachlor epoxide
DDE
Endrin
Endosulfan II
Dieldrin
Endosulfan sulfate
DDD
Chlordane
DDT
Toxaphene
Aroclor 1221
Aroclor 1254
Aroclor 1016
Aroclor 1232
Aroclor 1242
Aroclor 1248
Aroclor 1260

Inorganics
(Medium: Water/Soil/Sediment/Biota)
and
Fluoride and Nitrate
(Medium: Water)

Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Zinc
Fluoride
Nitrate

Note: 2,3,7,8-Tetrachlorodibenzo-p-dioxin was quantitatively determined in a select number of samples.

TABLE A-2. SUBSTANCES MONITORED IN LOVE CANAL AIR SAMPLES

Volatiles
(Source: TENAX)

Quantitative Analysis	Qualitative Analysis
Benzene	Chloroform
Carbon tetrachloride	1,2-Dichloroethane
Chlorobenzene	2,4-Dichlorotoluene
o-Chlorotoluene	o-Chlorobenzaldehyde
p-Chlorotoluene	p-Chlorobenzaldehyde
1,2-Dibromoethane	Benzyl chloride
o-Dichlorobenzene	(α-Chlorotoluene)
p-Dichlorobenzene	1,1-Dichloroethane
1,1,2,2-Tetrachloroethylene	1,1-Dichloroethylene
Toluene	(Vinylidene chloride)
	1,2-Dichloroethane (EDC)
	1,2-Dichloroethylene
	Dichloromethane
	Phenol
	o-Xylene
	m-Xylene
	p-Xylene

Pesticides and Other Compounds
(Source: PFOAM)

Quantitative Analysis	Qualitative Analysis
γ-BHC (Lindane)	Hexachloro-1,3-butadiene
Hexachlorobenzene	1,2,4,5-Tetrachlorobenzene
Hexachlorocyclopentadiene (C-56)	α,α,2,6-Tetrachlorotoluene
1,2,3,4-Tetrachlorobenzene	Pentachloro-1,3-butadiene
1,2,3-Trichlorobenzene	Pentachloronitrobenzene (PCNB)
1,2,4-Trichlorobenzene	1,2,3,5-Tetrachlorobenzene
1,3,5-Trichlorobenzene	α-Benzenehexachloride (α-BHC)
2,4,5-Trichlorophenol	Heptachlor
Pentachlorobenzene	

(continued)

TABLE A-2 (continued)

Inorganics (Source: HIVOL)
Quantitative Analysis
Antimony
Arsenic
Beryllium
Cadmium
Copper
Lead
Nickel
Zinc

Note: 2,3,7,8-Tetrachlorodibenzo-p-dioxin was quantitatively determined in a select number of samples.

APPENDIX B
COMPARATIVE DATA AND EXISTING STANDARDS FOR SUBSTANCES MONITORED AT LOVE CANAL

COMPARATIVE DATA

The Love Canal multimedia environmental monitoring program included sampling at control sites selected specifically for the purpose of collecting comparative data that permitted the testing of statistical hypotheses rergarding the extent and degree of Love Canal-related contamination in the Declaration Area. Due to limited availability of appropriate control sites and the relatively short time period during which this study was to be conducted, the number of control sites samples that could be collected was (in certain instances) restricted. An enumeration of control sites locations for selected medium/source/location combinations is presented in Table B-1.

NONCONTEMPORARY COMPARATIVE DATA

The Love Canal monitoring program was designed to include a control area, in this case a site-specific control. Another useful kind of control, however, is background data on concentrations of various chemicals in pertinent media from around the nation.

The principal problem in assembling data on national background concentrations is the lack of routine monitoring networks for many of the chemicals of interest. Most of the data on organic chemicals, for example, were collected for regulatory purposes, compliance, or enforcement, and are therefore related to unusually high discharges or leakage of chemicals from known sources.

There are, however, some nationwide monitoring networks that are sources of useful data. Examples are: (1) the National Air Sampling Network, (NASN) which collects data on metals in air samples; (2) the National Organics Reconnaissance Survey (NORS) for organics in drinking water; and (3) the National Urban Soil Network (NUSN) for pesticides in soil. Other than data from such networks, only various research projects proved fruitful.

TABLE B-1. CONTROL SITES

Site Code	Address
	Ground Water - A Wells (Shallow System)
99015	95th Street, Niagara Falls (near DeMunda Avenue)
99016	Cayuga Drive, Niagara Falls (near 98th Street)
99017	Cayuga Drive, Niagara Falls (near 95th Street)
99072	Jayne Park, Niagara Falls (near South 86th Street)
99550	Deuro Drive, Niagara Falls (near Brookhaven Drive)
99551	91st Street, Niagara Falls (near Colvin Boulevard)
99552	92nd Street, Niagara Falls (near Read Avenue)
99553	91st Street, Niagara Falls (near Read Avenue)
99554	Pasadena Avenue, Niagara Falls (near Lindbergh Avenue)
99555	Luick Avenue, Niagara Falls (near 91st Street)
99559	Griffon Park, Niagara Falls
	Ground Water - B Wells (Bedrock)
99015	95th Street, Niagara Falls (near DeMunda Avenue)
99016	Cayuga Drive, Niagara Falls (near 98th Street)
99017	Cayuga Drive, Niagara Falls (near 95th Street)
99033	Jayne Park, Niagara Falls (near South 91th Street)
99034	Buffalo Avenue, Niagara Falls (near 88th Street)
99072	Jayne Park, Niagara Falls (near South 86th Street)
99550	Deuro Drive, Niagara Falls (near Brookhaven Drive)
99551	91st Street, Niagara Falls (near Colvin Boulevard)
99553	91st Street, Niagara Falls (near Read Avenue)
99555	Luick Avenue, Niagara Falls (near 91st Street)
99556	Brookside Avenue, Niagara Falls (near 90th Street)
99558-B1	Williams Road, Town of Wheatfield (near Robert Moses Pkwy.)
99558-B2	Williams Road, Town of Wheatfield (near Robert Moses Pkwy.)
99559	Griffon Park, Niagara Falls
99560	Williams Road, Town of Wheatfield (near Robert Moses Pkwy.)
	Soil
99008	Frontier Avenue, Niagara Falls (near 82nd Street)
99010	82nd Street, Niagara Falls (near Laughlin Drive)
99012	60th Street, Niagara Falls (near Lindbergh Avenue)
99017	Cayuga Drive, Niagara Falls (near 95th Street)
99020	Stony Point Road, Grand Island (near Love Road)
99021	West River Parkway, Grand Island (near White Haven Road)
99022	Pierce Avenue, Niagara Falls (near 22nd Street)
99023	Packard Road, Town of Niagara (near Young Street)
99051	Woodstock Road, Grand Island (near Long Road)

(continued)

TABLE B-1 (continued)

Site Code	Address
	Sump Water
99021	West River Parkway, Grand Island (near White Haven Road)
	Storm Sewer Water and Sediment
99529	91st Street, Niagara Falls (near Bergholtz Creek)
	Surface Water and Stream Sediment
99004	Bergholtz Creek, Town of Wheatfield (near Williams Road)
99005	Black Creek, Town of Wheatfield (near Williams Road)
99025	Cayuga Creek, Niagara Falls (near Cayuga Drive)
99035	Fish Creek, Town of Lewiston (near Upper Mountain Road)
99073	Niagara River (approximately coincident with the imaginary extension of 102nd Street, Niagara Falls)
	Air
99020	Stony Point Road, Grand Island (near Love Road)
99021	West River Parkway, Grand Island (near White Haven Road)
99022	Pierce Avenue, Niagara Falls (near 22nd Street)
99023	Packard Road, Town of Niagara (near Young Street)

In evaluating the quality of the reported data, three designations are used: high quality (Q), which has excellent quality control procedures; research quality (R), which has very good quality control; and uncertain (U), which has unknown quality control, but has results consistent with other published data. These designations are indicated for each entry in the following tables.

The tables that follow are of two types. One type (Table B-2) is nationwide average data that could not be related to specific monitoring locations. The other type (Tables B-3 through B-5) is reported by city, where the cities have been aggregated according to commercial cities (no significant industry), industrial cities, and chemical cities (significant chemical industries). Some of the cities included in the three categories are:

Commercial	Industrial	Chemical
Honolulu, HI	Pittsburgh, PA	Edison, NJ
Cheyenne, WY	Birmingham, AL	Baltimore, MD
Sacramento, CA	Gary, IN	Houston, TX
Phoenix, AZ	St. Louis, MO	Belle, WV
Ogden, UT	Cincinnati, OH	Pasadena, TX
Cedar Rapids, IA	Detroit, MI	Passaic, NJ

Very little data were identified for the types of samples collected in the biomonitoring program (dog and mice hair, mice tissues, worm and crayfish tissues, and silver maple leaves). No analyses of such samples for organics were located. The few analyses for metals that were located are presented in Table B-6.

The five tables of comparative data that follow include the following information:

Chemical--the name of the chemical detected.
Range--the range of mean values reported.
Qual.--the quality of the data (Q,R,U) explained above.
Max.--the maximum value reported. A blank indicates maximum unknown.
No.--the number of cities in that category.
Time--the years in which analyses occurred.

Table B-2 summarizes the U.S. average data that consists of research quality, in general, and which were collected between 1964 and 1979.

BIBLIOGRAPHY

Air Quality Data for Metals 1976 from the NASN. EPA-600/4-79-054.

Ambient Air Carcinogenic Vapors--Improved Sampling and Analytical Techniques and Field Studies. EPA-600/2-79-008.

Analysis of EPA Pesticides Monitoring Networks. EPA-560/13-79-014.

Benzo-a-Pyrene data from SAROAD.

Biological Monitoring for Environmental Pollutants. EPA-600/3-80-089 to 092.

Cycling and Control of Metals, Proceedings of a Conference, NERC-Cincinnati. February 1973.

Geochemical Environment in Relation to Health and Disease. Ann. N.Y. Acad. Sci., vol. 199. 1972.

Monitoring to Detect Previously Unrecognized Pollutants in Surface Waters. EPA-560/6-77-015.

National Organics Reconnaissance Survey for Halogenated Organics. JAWWA 67: 643-47. 1975.

Water Quality Criteria Data Book. Vol. 1 and Vol. 2. 1970-71.

TABLE B-2. U.S. AVERAGE DATA (ppb)

Chemical	Soil Mean or Range	Sediment Range	Drinking Water Range	Surface Water Range
Antimony			<2-100	
Arsenic	5ppm		<10-20	10-100
Barium			<1-200	
Beryllium	6ppm		<.01-<5	
Cadmium	0.3ppm		<0.1-9	1-130
Chromium	5-1,000ppm		<0.1-11	
Copper	1-200ppm		<0.4-980	
Lead	15ppm		<0.1-100	1-80
Nickel			<0.1-10	
Mercury	0.071ppm		<0.5-<10	0.1-20
Selenium	0.1-200ppm			
Zinc	10-300ppm		<10-3,000	
Lindane				0.005-0.76
Heptachlor				0.005-0.031
Aldrin				0.001-0.26
Heptachlor epoxide	1-6			0.001-0.067
Endrin				0.005-0.94
Dieldrin	1-8	0.43-1.99		0.003-0.17
Chlordane	2-117	3.1-21.7		0.006-0.075
Toxaphene				0.5-0.75
ΣDDT	5-175	1.71-5.77		0.012-0.292
PCB		2.2-48.2		0.006-0.12
Trichloroethene			0.06-3.2	0.1-42
Carbon tetrachloride			0.1-30	0.2-10
Tetrachloroethene			0.1-21	0.1-9
1,1,1-Trichloroethane			0.1-3.3	0.1-1.2
1,2-Dichloroethane			0.8-4.8	0.1-45
Vinyl chloride			0.1-9.8	0.2-5.1
Methylene chloride			0.2-13	0.4-19

TABLE B-3. AIR

($\mu g/m^3$)

Chemical	Commercial Cities				Industrial Cities				Chemical Cities				Time
	Range	Max.	Qual.	No.	Range	Max.	Qual.	No.	Range	Max.	Qual.	No.	
α-BHC	0.0009-0.002		Q	3	0.0006-0.002		Q	5					1975-77
Lindane	0.0002-0.001		Q	3	0.0003-0.002		Q	5					1975-77
Heptachlor	0.0001-0.005		Q	3	0.0003-0.009		Q	5					1975-77
Dieldrin	0.0002-0.0004		Q	3	0.0002-0.002		Q	5					1975-77
Chlordane	0.0008-0.018		Q	2	0.003-0.031		Q	5					1975-77
ΣDDT	0.002		Q	1	0.005-0.006		Q	2					1975-77
PCB	0.004-0.068		Q	2	0.003-0.011		Q	3					1975-77
Methylene chloride					0.69	1.1	R	1	0.7-35	100	R	5	1976-77
1,1-Dichloroethane									0.15-22.7		R	3	1976-77
Vinyl chloride									2.4		R	1	1976-77
Chloroform					ND-0.44	1.1	R	2	T-7.8	11.1	R	7	1976-77
1,2-Dichloroethane					0.3	0.4	R	1	0.022-1.1	9.5	R	7	1976-77
1,2-Dichloroethene									0.25-3.4	5.3	R	3	1976-77
1,1,1-Trichloroethane					ND-1.07	2.3	R	2	T-1.9	7.7	R	7	1976-77
Carbon tetrachloride					ND-0.09		R	2	0.08-2.5	13.7	R	7	1976-77
Trichloroethene					ND-0.11	0.13	R	2	0.07-2.96	10.6	R	7	1976-77
1,1,2-Trichloroethane									0.22	4.5	R	1	1976-77
1,1,2,2-Tetrachloroethane									0.74	1.4	R	1	1976-77
Benzyl chloride									0.34	8.0	R	1	1976-77
Tetrachloroethene					ND-0.066		R	2	0.02-1.77	9.2	R	6	1976-77
Chlorobenzene					ND-0.28	1.0	R	2	ND-0.45	2.6	R	7	1976-77
1,4-Dichlorobenzene					ND-0.21	0.35	R	2	0.008-0.75		R	6	1976-77
1,3-Dichlorobenzene					ND-0.24	0.56	R	2	0.015-0.29		R	6	1976-77
Hexachlorobutadiene					ND		R	1	0.07	0.12	R	1	1976-77
Trichlorebenzenes					ND		R	1	ND-0.065	1.16	R	2	1976-77
Benzo-a-pyrene	0.0003	0.0009	U	1	0.0001-0.002	0.004	U	7	0.0001-0.0006	0.0015	U	4	1977-78
Arsenic	ND-0.1		U	4	ND-0.1		U	5					1978-79
Barium	0.02-0.06	0.24	U	5	0.01-0.08	0.37	U	10	0.02-0.36	1.16	U	8	1978-79
Beryllium	0.00019-0.00037	0.00055	U	7	0.00018-0.00033	0.00098	U	10	0.0001-0.0003	0.0013	U	9	1978-79
Cadmium	0.002	30.18	U	1	0.009-0.035	0.046	Q	4	ND-0.001	0.071	U	9	1978-79
Chromium	0.005-0.026	0.043	Q	4	0.004-0.016	0.021	Q	7	0.005-0.034	0.072	Q	7	1978-79
Copper	0.067-0.53	0.83	Q	7	0.055-0.54	0.79	Q	11	0.068-0.31	0.35	Q	8	1978-79
Lead	0.54-1.55	4.19	Q	7	0.22-1.23	1.71	Q	11	0.83-1.84	3.44	Q	8	1978-79
Nickel	0.004-0.041	0.079	Q	7	0.004-0.033	0.05	Q	11	0.004-0.047	0.060	Q	9	1978-79
Zinc	0.0001-0.138	0.44	U	6	0.054-0.475	0.96	U	10	0.06-0.272	0.77	U	9	1978-79

ND: Below limit of detection

TABLE B-4. SURFACE WATER (μg/liter)
(1976)

Chemical	Industrial Cities			Chemical Cities		
	Range	Qual.	No.	Range	Qual.	No.
Chloroform	1-43	R	6	1-87	R	4
1,2-Dichloroethane				1-9	R	3
1,1,1-Trichloroethane				2	R	1
Bromodichloromethane	4-7	R	2	1-8	R	2
Trichloroethene	300	R	1	1-4	R	3
Benzene	270	R	1	1	R	1
Dibromochloromethane	4-8	R	1	4	R	3
1,1,2,2-Tetrachloroethane	1	R	2	1	R	1
Tetrachloroethene	1	R	1	1-5	R	2
Pentachlorophenol	4	R	1			
1,4-Dichlorobenzene	10	R	1	21	R	1
Di(2-ethylhexyl)phthalate	1-150	R	5	2-5	R	4
Di-n-butylphthalate				1-4	R	3

TABLE B-5. DRINKING WATER (μg/liter)
(1975)

Compound	Commercial Cities			Industrial Cities			Chemical Cities		
	Range	Qual.	No.	Range	Qual.	No.	Range	Qual.	No.
Chloroform	0.4-311	Q	9	4-93	Q	12	0.6-86	Q	7
1,2-Dichloroethane	T	Q	3	T-0.4	Q	5	T-6	Q	4
Carbon Tetrachloride				T-2	Q	3	T-3	Q	3
Bromodichloromethane	0.9-29	Q	8	0.8-28	Q	11	T-16	Q	7
Dibromochloromethane	T-16	Q	7	T-17	Q	10	T-5	Q	7
Bromoform	2-3	Q	3	T-1	Q	3			

T: Trace

TABLE B-6. BIOTA (μg/kg)

Element	Silver Maple Leaf Concentrations	Silver Maple Leaf Qual.	Mouse Hair Range	Mouse Hair Qual.
Antimony			1,300	R
Cadmium	0.1	R		
Chromium	0.3	R	5,600-8,200	R
Mercury			<8	R
Selenium			200-27,000	R

Tables B-7 and B-8 contain the results from EPA sponsored ambient air monitoring studies. Table B-7 presents the results, in nanograms per cubic meter (ng/m), of measurements in ambient air for the substances listed conducted by Research Triangle Institute, as well as the results of other EPA studies (References 1, 2, and 3). Table B-8 presents the results from a study conducted for EPA of air samples collected near the downtown areas of Los Angeles and Oakland, California, and Phoenix, Arizona. This study incorporated the use of gas chromatography with electron capture detector (ECD), or flame ionization detector (FID), for measurement purposes.

REFERENCES FOR TABLES B-7 AND B-8

1. Pellizzari, E. D. and J. E. Bunch. Ambient Air Carcinogenic Vapors. Improved Sampling and Analytical Techniques and Field Studies. EPA-600/2-79-081. May 1979.

2. Pellizzari, E. D. Analysis of Organic Air Pollutants by Gas Chromatography and Mass Spectroscopy. Final Report. EPA-600/2-79-057. March 1979.

3. Interim Report on Monitoring Methods Development in the Beaumont-Lake Charles Area. EPA 600/4-80-046. October 1980 (author not listed).

4. Singh, H. B., L. J. Salas, A. Smith, and H. Shigeishi. Atmospheric Measurements of Selected Toxic Organic Chemicals: Halogenated Alkanes; Chlorinated Ethylenes, Chlorinated Aromatics, Aromatic Hydrocarbons, and Secondary Organics. Interim Report, Grant No. 805990, SRI Project 7774, SRI International. April 1980.

Table B-9 summarizes the current standards for some of the organic compounds and elements monitored in air at Love Canal. The information reported in Table B-9 includes standards of the U.S. Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH), and recommended exposure limits of the American Conference of Governmental Industrial Hygienists (ACGIH). The occupational standards reported here are presented for informational purposes only, and are not to be interpreted as applicable directly to acceptable household or ambient exposure levels.

Table B-10 presents the analytical results from the National Organics Reconnaissance Survey of Halogenated Organics (NORS) and the National Organics Monitoring Survey (NOMS) of drinking water supplies. The table contains findings for chloroform, bromoform, bromodichloromethane, dibromochloromethane, and total trihalomethane concentrations in the water supplies of 80 U.S. cities (NORS) and 113 public water systems (NOMS).

The EPA national drinking water regulations are presented in Table B-11. Table B-11 includes both the national interim primary drinking water regulations as well as the recommended national secondary drinking water regulations.

TABLE B-7. LIST OF COMPOUNDS FOUND IN AMBIENT AIR USING TENAX

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Vinyl chloride	Clifton, NJ	400	1
	Passaic, NJ	120,000	1
	Belle, WV	2-4,000	1
	Nitro, WV	50,000	1
	Deer Park, TX	100	1
	Plaquemine, LA	30-1,334	1
Ethyl chloride	Plaquemine, LA	1,378	1
Vinylidene chloride (1,1-Dichloroethylene)	Edison, NJ	T(454)	1
	Bridgeport, NJ	T(303)	1
	Linden, NJ	T(263)	1
	Staten Island, NY	T(263)	1
	Charleston, WV	T(263)	1
	Front Royal, VA	T(500)-2,500	1
	Bristol, PA	T(333)	1
	N. Philadelphia, PA	T(263)	1
	Marcus Hook, PA	T(263)	1
	Plaquemine, LA	36-990	1
	Geismar, LA	T-200	1
	Liberty Mounds, OK	T	1
	Houston, TX	T-430	1
Ethyl bromide	Edison, NJ	T-1,000	1
	Eldorado, AK	T	1
	Magnolia, AK	T	1
Methylene chloride	Paterson, NJ	1,091	1
	Clifton, NJ	1,545	1
	Passaic, NJ	400	1
	Hoboken, NJ	T	1
	Fords, NJ	9,286	1
	Edison, NJ	T-1,250,000	1
	E. Brunswick, NJ	T(1,000)-125,000	1
	Sayreville, NJ	T-7,600	1
	Linden, NJ	T(500)-26,778	1
	Deepwater, NJ	35-625	1
	Burlington, NJ	T(1,000)	1
	Bridgeport, NJ	T(555)-1,000	1
	Staten Island, NY	9778-19,500	1
	Niagara Falls, NY	44-11,556	1
	Belle, WV	8,700	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Methylene chloride (continued)	Nitro, WV	T(555)-50,000	1
	South Charleston, WV	T(714)-11,334	1
	Bristol, PA	T(571)	1
	N. Philadelphia, PA	T(555)-560	1
	Marcus Hook, PA	T(555)-1,000	1
	Charleston, WV	T(1,000)-2,818	1
	St. Albans, WV	T(714)-778	1
	W. Belle, WV	T(714)-1,778	1
	Institute, WV	1,636-4,091	1
	Front Royal, VA	T(714)-238,250	1
	Birmingham, AL	T(715)-1,000	1
	Geismar, LA	442-2,333	1
	Baton Rouge, LA	160-2,160	1
	Houston, TX	0-4,300	1
	Magna, UT	T(714)-23,714	1
	Upland, CA	1,800-42,000	1
1,2-Dichloro-ethylene	E. Brunswick, NJ	4,847	1
	Edison, NJ	T(565)-5,263	1
	Niagara Falls, NY	T(29)-334	1
	St. Albans, WV	T(263)	1
	W. Belle, WV	T(263)	1
	S. Charleston, WV	T(213)	1
	Nitro, WV	T(213)	1
	Institute, WV	T(213)	1
	Front Royal, VA	T(213)-2,974	1
	Magna, UT	T(334)	1
	Grand Canyon, AR	260	1
Chloroprene isomer	Sayreville, NJ	4,067	1
3-Chloropropene	Edison, NJ	T-28,667	1
1,1-Dichloro-ethane	Edison, NJ	22,700	1
	Linden, NJ	229	1
	Deer Park, TX	555	1
	Plaquemine, LA	T-478	1
	Geismar, LA	75,500	1
	Baton Rouge, LA	34-477	1
	Lake Charles, LA	3,015-10,443	3
	Magna, UT	T(334)	1
Chloroform	Paterson, NJ	3,750	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Chloroform (continued)	Clifton, NJ	8,300	1
	Passaic, NJ	4,167	1
	Hoboken, NJ	2,083	1
	Newark, NJ	37,000	1
	Staten Island, NY	144-20,830	1
	Fords, NJ	16,700	1
	Bound Brook, NJ	4,167	1
	E. Brunswick, NJ	186-20,000	1
	Edison, NJ	T(230)-266,000	1
	Sayreville, NJ	9,000-30,000	1
	Linden, NJ	T(75)-1,178	1,2
	Deepwater, NJ	T-439	1,2
	Burlington, NJ	T(167)	1
	Bridgeport, NJ	250	1
	Niagara Falls, NY	464-13,484	1
	S. Charleston, WV	T(125)-2,161	1
	Nitro, WV	T(125)-39,000	1
	Bristol, PA	150-250	1
	N. Philadelphia, PA	T(97)	1
	Front Royal, VA	T(125)-14,517	1
	Marcus Hook, PA	T(97)-235	1
	Charleston, WV	T(167)	1
	St. Albans, WV	T(125)	1
	W. Belle, WV	T(125)	1
	Birmingham, AL	T(125)-1,000	1
	Houston, TX	T(125)-11,538	1
	Pasadena, TX	T	1
	Deer Park, TX	T-53,846	1
	Freeport, TX	T-280	1
	La Porte, TX	7,692-8,850	1
	Plaquemine, LA	419-5,800	1,2
	Geismar, LA	857-11,742	1
	Baton Rouge, LA	181-6,968	1,2
	Magna, UT	T(125)	1
	Upland, CA	400-14,000	1
1,2-Dichloroethane	Paterson, NJ	T	1
	Clifton, NJ	64,516	1
	Passaic, NJ	T	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
1,2-Dichloroethane (continued)	Hoboken, NJ	T	1
	Newark, NJ	T	1
	Fords, NJ	T	1
	Bound Brook, NJ	T	1
	Edison, NJ	T(347)-57,000	1
	Sayreville, NJ	37,913	1
	E. Brunswick, NJ	T(150)	1
	Linden, NJ	T(151)-101	1,2
	Deepwater, NJ	T-53	1,2
	Burlington, NJ	T	
	Bridgeport, NJ	T(195)	
	Staten Island, NY	T(195)	1
	St. Albans, WV	T(334)	1
	W. Belle, WV	T(213)	1
	Charleston, WV	T(212)	1
	Nitro, WV	T(151)	1
	S. Charleston, WV	T(263)	1
	Institute, WV	T(213)	1
	Front Royal, VA	T(213)-2,974	1
	Bristol, PA	T(258)	1
	N. Philadelphia, PA	T(195)-960	1
	Marcus Hook, PA	T(195)	1
	Birmingham, AL	200-400	1
	Houston, TX	T(258)-242	1
	Pasadena, TX	158	1
	Deer Park, TX	T-66,300	1
	Freeport, TX	3,300-4,500	1
	La Porte, TX	778	1
	Plaquemine, LA	10-3,700	1
	Geismar, LA	100-10,333	1
	Baton Rouge, LA	78-10,341	1
	Lake Charles, LA	21-1,240	1
	Magna, UT	T(334)	1
	Dominquez, CA	14,814	1
	Upland, CA	T(277)860	1
1,1,1-Trichloroethane	Paterson, NJ	T	1
	Clifton, NJ	T	1
	Passaic, NJ	13,000	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
1,1,1-Trichloroethane (continued)	Hoboken, NJ	T	1
	Newark, NJ	T	1
	Staten Island, NY	T	1
	Fords, NJ	T	1
	Bound Brook, NJ	T	1
	Edison, NJ	T(417)-500,000	1
	E. Brunswick, NJ	T(417)	1
	Sayreville, NJ	T-30	1
	Linden, NJ	T-3,116	1
	Deepwater, NJ	T-2,842	1
	Burlington, NJ	T(294)	1
	Bridgeport, NJ	129-650	1
	Niagara Falls, NJ	T(334)-3,890	1
	S. Charleston, WV	T(312)-5,000	1
	Bristol, PA	T(267)	1
	N. Philadelphia, PA	T(277)	1
	Marcus Hook, PA	T-1,600	1
	Charleston, WV	T(217)-278	1
	St. Albans, WV	T(334)	1
	Nitro, WV	T(334)	1
	W. Belle, WV	T(312)	1
	Institute, WV	T(217)-347	1
	Front Royal, VA	T(100)-2,933	1
	Birmingham, AL	T(334)-2,267	1
	Houston, TX	522-995	1
	Pasadena, TX	T	1
	Deer Park, TX	144-1,000	1
	Freeport, TX	15,200-16,600	1
	La Porte, TX	T-27,700	1
	Plaquemine, LA	68-8700	1
	Geismar, LA	T-675	1
	Baton Rouge, LA	78-500	1
	Liberty Mounds, OK	T-(417)	1
	Tulsa, OK	T(334)	1
	Vera, OK	T(334)	1
	Beaumont, TX	727-8,381	3
	Lake Charles, LA	32-35,000	1,3
	Magna, UT	T(334)	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
1,1,1-Trichloro-ethane (continued)	Grand Canyon, AR	T(217)-218	1
	Los Angeles, CA	8340	1
	Upland, CA	T(454)-51,721	1
Carbon tetrachloride	Paterson, NJ	T	1
	Clifton, NJ	T(59)	1
	Passaic, NJ	T	1
	Hoboken, NJ	T	1
	Newark, NJ	T	1
	Staten Island, NY	T(74)	1
	Fords, NJ	334	1
	Bound Brook, NJ	T	1
	East Brunswick, NJ	T(120)-20,000	1
	Edison, NJ	T-13,687	1
	Sayreville, NJ	T(125)	1
	Linden, NJ	T-71	1
	Deepwater, NJ	19-32	1
	Burlington, NJ	T(125)	1
	Bridgeport, NJ	T(74)	1
	Niagara Falls, NY	T(83)-5,038	1
	S. Charleston, WV	T(95)-2,222	1
	Bristol, PA	T(95)	1
	N. Philadelphia, PA	T(74)	1
	Marcus Hook, PA	T(74)	1
	Nitro, WV	T(95)	1
	W. Belle, WV	T(91)	1
	St. Albans, WV	T(74)-3,630	1
	Institute, WV	T(59)-441	1
	Front Royal, VA	T(59)-1,190	1
	Houston, TX	T(87)-238	1
	Pasadena, TX	T-146	1
	Deer Park, TX	T-846	1
	Freeport, TX	T-11,538	1
	La Porte, TX	T-1,230	1
	Plaquemine, LA	T-4,628	1
	Geismar, LA	183-10,100	1
	Baton Rouge, LA	74-1,037	1
	Liberty Mounds, OK	T	1
	Tulsa, OK	T	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)†	Ref.
Carbon tetrachloride (continued)	Vera, OK	T	1
	Beaumont, TX	611-16,380	3
	Lake Charles, LA	30-10,154	1,3
	Magna, UT	T(95)-166	1
	Grand Canyon, AR	T(59)	1
	Upland, CA	T(134)-1,461	1
Dibromomethane	Paterson, NJ	130	1
	Edison, NJ	63,000	1
	E. Brunswick, NJ	42	1
1-Chloro-2-bromoethane	Edison, NJ	5,000-27,000	1
	El Dorado, AK	T-73	1
	Magnolia, AK	32-1,089	1
1,1,2-Trichloroethane	Edison, NJ	294-17,571	1
	Sayreville, NJ	3,500	1
	Edison, NJ	4,467	1
	Linden, NJ	200	1
	Deer Park, TX	3,334-6,700	1
	Freeport, TX	T-3,821	1
	Plaquemine, LA	36-1,840	1
	Geismar, LA	120-9,611	1
	Baton Rouge, LA	54-553	1
	Lake Charles, LA	3,500-40,400	3
Trichloroethylene	Paterson, NJ	1,200	1
	Clifton, NJ	T	1
	Passaic, NJ	T	1
	Hoboken, NJ	T	1
	Staten Island, NY	T(73)	1
	Bound Brook, NJ	T	1
	Edison, NJ	T(178)-93,000	1
	E. Brunswick, NJ	T-82,000	1
	Sayreville, NJ	T-3,737	1
	Linden, NJ	T-242	1
	Deepwater, NJ	4-56	1
	Burlington, NJ	T(92)	1
	Bridgeport, NJ	T(77)	1
	Niagara Falls, NY	T(73)-15,880	1
	Charleston, WV	T(56)	1
	S. Charleston, WV	T(55)-179	1

(continued)

---

†T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)†	Ref.
Trichloroethylene (continued)	Nitro, WV	T(55)-360	1
	St. Albans, WV	T(98)-45	1
	Bristol, PA	T(100)	1
	N. Philadelphia, PA	T(92)	1
	Marcus Hook, PA	T(80)	1
	W. Belle, WV	T(55)	1
	Institute, WV	T(55)	1
	Front Royal, VA	T(74)-420	1
	Birmingham, AL	T(100)-134	1
	Houston, TX	T(100)-160	1
	Pasadena, TX	76-5,071	1
	Deer Park, TX	321	1
	Freeport, TX	0-200	1
	La Porte, TX	T-43	1
	Baton Rouge, LA	T(132)	1
	Lake Charles, LA	392-6,000	3
	Beaumont, TX	0-1,034	3
	Liberty Mounds, OK	T	1
	Tulsa, OK	T	1
	Magna, UT	T(100)	1
	Grand Canyon, AR	T(130)	1
	Dominquez, CA	9,210	1
	Upland, CA	T(167)-3,400	1
1,2-Dibromoethane	Sayreville, NJ	591	1
	Edison, NJ	T-757	1
	Deepwater, NJ	T	1
	Beaumont, TX	0-1,000	3
	El Dorado, AK	T-271,283	1
	Magnolia, AK	26-62,484	1
Tetrachloroethylene	Paterson, NJ	T	1
	Clifton, NJ	T	1
	Passaic, NJ	T	1
	Hoboken, NJ	T	1
	Newark, NJ	T	1
	Staten Island, NY	T	1
	Fords, NJ	T	1
	Bound Brook, NJ	T	1
	Edison, NJ	T-394,000	1

(continued)

---

† T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)†	Ref.
Tetrachloroethylene (continued)	E. Brunswick, NJ	T-2,722	1
	Sayreville, NJ	T(49)-60,000	1
	Deepwater, NJ	T-218	1
	Burlington, NJ	185	1
	Bridgeport, NJ	T(189)-276	1
	Linden, NJ	T(106)-960	1
	Niagara Falls, NY	T(155)-51,992	1
	Charleston, WV	T(19)-109	1
	S. Charleston, WV	T(35)-1,536	1
	St. Albans, WV	T(26)-434	1
	Nitro, WV	T(19)-52	1
	W. Belle, WV	T(19)	1
	Institute, WV	T(19)	1
	Front Royal, VA	T(19)-2,994	1
	Birmingham, AL	T(25)-58	1
	Houston, TX	T(44)-260	1
	Pasadena, TX	T-20	1
	Deer Park, TX	T-2,019	1
	Freeport, TX	0-1,585	1
	La Porte, TX	T-83	1
	Lake Charles, LA	T-10,547	3
	Beaumont, TX	0-3,900	3
	Plaquemine, LA	T-1,224	1
	Geismar, LA	7-100	1
	Baton Rouge, LA	T(59)-364	1
	Liberty Mounds, OK	T	1
	Tulsa, OK	T	1
	Vera, OK	T	1
	Magna, UT	T(34)-80	1
	Grand Canyon, AR	T(234)	1
	Dominquez, CA	20,000	1
	Upland, CA	70-7,258	1
Chlorobenzene	Paterson, NJ	T	1
	Clifton, NJ	T	1
	Hoboken, NJ	T	1
	Newark, NJ	T	1
	Staten Island, NY	T(135)	1
	Fords, NJ	T	1
	Bound Brook, NJ	20,000	1

(continued)

---

†T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Chlorobenzene (continued)	E. Brunswick, NJ	T(77)-1,127	1
	Edison, NJ	T(60)-12,791	1
	Sayreville, NJ	T(60)-4,000	1
	Linden, NJ	T-272	1
	Deepwater, TX	11-512	1
	Burlington, NJ	T(278)	1
	Bridgeport, NJ	T(231)	1
	Niagara Falls, NY	T(197)-4,232	1
	S. Charleston, WV	T(18)	1
	Nitro, WV	T(18)	1
	Charleston, WV	T(18)	1
	W. Belle, WV	T(18)	1
	Bristol, PA	450	1
	N. Philadelphia, PA	T(238)	1
	Marcus Hook, PA	T(242)	1
	Institute, WV	T(18)	1
	Front Royal, VA	T(18)	1
	Birmingham, AL	38-122	1
	Plaquemine, LA	29	1
	Geismar, LA	T-900	1
	Baton Rouge, LA	T(128)	1
	Houston, TX	T(132)-125	1
	Lake Charles, LA	7-29	1,3
	Beaumont, TX	T-1100	3
	Magna, UT	T(100)	1
	Grand Canyon, AR	T(104)	1
	Upland, CA	T(136)-152	1
1,1,2,2-Tetrachloroethane	Edison, NJ	1,389-2,2785	1
	Baton Rouge, LA	0-71	2
	Iberville Parish, LA	0-5,800	2
	Lake Charles, LA	37-430	3
Chlorotoluene isomer(s)	Niagara Falls, NY	25-226,514	1
	Iberville Parish, LA	0-35	2
Pentachloroethane	Linden, NJ	76	1
	Iberville Parish, LA	0-13	2
m-Dichlorobenzene	Clifton, NJ	T(33)	1
	Hoboken, NJ	T(33)	1
	Newark, NJ	T(33)	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
m-Dichlorobenzene (continued)	Bound Brook, NJ	T(33)	1
	Edison, NJ	T(49)-33,783	1
	East Brunswick, NJ	T(33)-659	1
	Sayreville, NJ	T(72)-126	1
	Linden, NJ	T-78	1
	Deepwater, NJ	T-1,240	1
	Burlington, NJ	T(185)	1
	Bridgeport, NJ	T(154)	1
	Staten Island, NY	T(90)	1
	S. Charleston, WV	T-38	1
	St. Albans, WV	T(18)	1
	Nitro, WV	T(20)	1
	Institute, WV	T(12)	1
	W. Belle, WV	T(9)	1
	Front Royal, VA	T(17)-279	1
	Bristol, PA	T(172)	1
	N. Philadelphia, PA	T(167)	1
	Marcus Hook, PA	T(161)	1
	Charleston, WV	101	1
	Birmingham, AL	T(94)-557	1
	Baton Rouge, LA	T(85)	1
	Houston, TX	T(83)	1
	El Dorado, AK	16	1
	Lake Charles, LA	6-27	1,3
	Magna, UT	T(69)	1
	Grand Canyon, AR	T(260)	1
	Upland, CA	T(26)-382	1
o-Dichlorobenzene	Edison, NJ	T(49)-12,433	1
	East Brunswick, NJ	T(33)-1,500	1
	Sayreville, NJ	T	1
	Linden, NJ	T-89	1
	Deepwater, NJ	T-1,319	1
	Burlington, NJ	T(185)	1
	Bridgeport, NJ	T	1
	Staten Island, NY	T(90)	1
	South Charleston, WV	T(17)-309	1
	Nitro, WV	T(9)-39	1
	St. Albans, WV	T(23)	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
o-Dichlorobenzene (continued)	W. Belle, WV	T(8)	1
	Institute, WV	T(9)-59	1
	Front Royal, VA	T(13)-58	1
	Bristol, VA	T(172)	1
	N. Philadelphia, PA	T(167)-185	1
	Baton Rouge, LA	T(84)	1
	Tulsa, OK	T	1
	Houston, TX	T(86)	1
	Lake Charles, LA	T	1,3
	Upland, CA	T(26)	1
Dichlorobenzene isomers	Fords, NJ	T	1
	Bound Brook, NJ	T	1
	Linden, NJ	T-30	2
	Deepwater, NJ	T-1,240	2
	Niagara Falls, NY	T(29)-100,476	1
	Liberty Mounds, OK	80	1
	Tulsa, OK	T	1
Chlorobenzaldehyde isomers	Niagara Falls, NY	T(18)-4,058	1
Bromotoluene isomer	Edison, NJ	472-1,873	1
	Niagara Falls, NY	T(53)-4372	1
Dichlorotoluene isomer(s)	Ford, NJ	T	1
	Deepwater, NJ	29-107	1
	Niagara Falls, NY	T(106)-158,682	1
Benzyl Chloride	Edison, NJ	4,513-8,033	1
Chloroaniline isomer	Bound Brook, NJ	33	1
	Deepwater, NJ	T-5,960	1
Trichlorobenzene isomer	Bound Brook, NJ	867	1
	Edison, NJ	1,160	1
	Linden, NJ	T-113	1
	Deepwater, NJ	T-150	1
	Niagara Falls, NY	T(23)-43,700	1
	Front Royal, VA	T(7)	1
	Bristol, PA	T(103)	1
	N. Philadelphia, PA	T	1
	Upland, CA	T(43)	1
	Deer Park, TX	25-2,000	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Trichlorobenzene isomer (continued)	Freeport, TX	8-13	1
	La Porte, TX	T	1
	Plaquemine, LA	20-40	1
	Baton Rouge, LA	23-117	1
1,3-Hexachloro-butadiene	Niagara Falls, NY	26-414	1
	Deer Park, TX	25-2,066	1
	Freeport, TX	T	1
	La Porte, TX	T	1
	Plaquemine, LA	18-37	1
	Baton Rouge, LA	23-117	1
	Lake Charles, LA	T-12	3
Chloronitrobenzene isomer	Deepwater, NJ	T-360	1
Dichloronitro-benzene isomer	Deepwater, NJ	T-2,704	1
Tetrachloro-benzene isomer(s)	Niagara Falls, NY	T(21)-9,600	1
Tetrachloro-toluene isomer(s)	Niagara Falls, NY	16-970	1
Pentachlorobenzene	Niagara Falls, NY	T(23)-494	1
2-Chloro-1,3-butadiene	Houston, TX	266-4,000	1
Bromopropane isomer	El Dorado, AK	T-47	1
	Magnolia, AK	T-734	1
Allyl bromide	El Dorado, AK	T-30	1
	Magnolia, AK	9-16	1
1,2-Dichloropropane	Geismar, LA	36-3,999	1
	Beaumont, TX	0-1,450	3
	Lake Charles, LA	23	1
	Iberville Parish, LA	0-2,200	2
Bromodichloro-methane	El Dorado, AK	T-26	1
	Magnolia, AK	T	1
Chlorodibromo-methane	El Dorado, AK	T-81	1
	Lake Charles, LA	34-230	1,3
Dichloropropane isomers	Deer Park, TX	T-2,586	1
	Freeport, TX	69-1,478	1
	Plaquemine, LA	T-2,239	1

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)[†]	Ref.
Dibromochloropropane isomer(s)	El Dorado, AK	T-187	1
	Magnolia, AK	25-6,653	1
Dichlorobutane isomer(s)	Plaquemine, LA	54-7,200	1,2
	Baton Rouge, LA	13-193	1,2
1-Chloro-2,3-dibromopropane	El Dorado, AK	T-20	1
1,1-Dibromo-2-Chloropropane	El Dorado, AK	T	1
1,2 & 1,3-Dibromopropane	El Dorado, AK	T	1
	Magnolia, AK	T	1
Dichlorodibromomethane	El Dorado, AK	7-40	1
Chlorobromopropane isomer	El Dorado, AK	T-83	1
1-Chloro-3-bromopropane	El Dorado, AK	T-23	1
	Magnolia, AK	T-1,688	1
1-Chloro-3-bromopropene	El Dorado, AK	T	1
Dichloropropene isomer	Deer Park, TX	T-1,293	1
	Plaquemine, LA	10-260	1
Bromoform	El Dorado, AK	T-104	1
	Magnolia, AK	8-380	1
	Lake Charles, LA	68-729	1,3
Bromobenzene	El Dorado, AK	T-4,276	1
	Magnolia, AK	23-140	1
Tetrachlorobutadiene	Iberville Parish, LA	0-17	2
Tetrachloropropane isomer	Iberville Parish, LA	0-240	2
Benzene	Iberville Parish, LA	420-16,000	2
	Baton Rouge, LA	80-11,000	2
	Beaumont, TX	900-33,333	3
	Linden, NJ	43-21,300	2
Acetone	Baton Rouge, LA	68-3,294	2
Cyanobenzene (benzonitrile)	Linden, NJ	T-49	2
	Deepwater, NJ	T-35	2
	Lake Charles, LA	19-62	3
Furan	Linden, NJ	9-46	2
	Deepwater, NJ	T-59	2

(continued)

[†] T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-7 (continued)

Compound	Location	Conc. Range (ng/m^3)†	Ref.
t-Butanol	Linden, NJ	87-1,745	2
iso-Propanol	Linden, NJ	4-59	2
Methylethyl ketone	Linden, NJ	T-84	2
Benzaldehyde	Linden, NJ	36-557	2
Acetophenone	Linden, NJ	131-1,167	2
	Lake Charles, LA	133-270	3
Methylvinyl ketone	Linden, NJ	10-45	2
	Deepwater, NJ	T-72	2
Cyclohexanone	Linden, NJ	T-629	2
Diethyl maleate	Linden, NJ	T-1,085	2
Diethyl fumarate	Linden, NJ	T-882	2
Tolualdehyde	Linden, NJ	T-83	2
Methylmethacrylate	Deepwater, NJ	16-95	2
Dibenzofuran	Deepwater, NJ	29-3,279	2
Phenylacetylene	Deepwater, NJ	T-41	2
Nitrobenzene	Deepwater, NJ	105-123	2
Aniline (or methylpyridine)	Deepwater, NJ	28	2
Chloroaniline isomer	Deepwater, NJ	T-5,960	2
Nitrophenol	Deepwater, NJ	24-73	2
o-Nitrotoluene	Deepwater, NJ	T-47	2
p-Nitrotoluene	Deepwater, NJ	59-86	2
1,2-Dibromopropane	Lake Charles, LA	23	3
Toluene	Lake Charles, LA	290-2,179	3
	Beaumont, TX	1378-32,157	3
Ethyl benzene	Lake Charles, LA	57-354	3
	Beaumont, TX	102-3,598	3
Naphthalene	Lake Charles, LA	56-118	3
Xylene(s)	Beaumont, TX	32-26,765	3
1-Methylnaphthalene	Lake Charles, LA	T-24	3
n-Nonanal	Lake Charles, LA	260-1,105	3
Ethyl acetate	Beaumont, TX	T-933	3

†T means trace; a number in parentheses by the T means estimated minimum detectable amount under the sampling and analysis conditions.

TABLE B-8. AVERAGE DAILY CONCENTRATIONS OF TOXIC CHEMICALS FOUND BY SINGH[†] (ppt)

Compounds	Los Angeles	Phoenix	Oakland
Methyl chloride	3,002	2,391	1,066
Methyl bromide	244	67	55
Methylene chloride	3,751	893	416
Chloroform	88	111	32
Carbon tetrachloride	215	277	169
1,2-Dichloroethane	519	216	83
1,2-Dibromoethane	33	40	16
1,1,1-Trichloroethane	1,028	824	291
1,1,2-Trichloroethane	9	16	8
1,1,1,2-Tetrachloroethane	4	9	4
1,1,2,2-Tetrachloroethane	17	17	7
Vinylidene chloride	5	30	13
Trichloroethylene	399	484	188
Tetrachloroethylene	1,480	994	308
Chlorobenzene	200	200	100
o-Dichlorobenzene	125	226	40
m-Dichlorobenzene	77	87	65
1,2,4-Trichlorobenzene	69	31	30
Benzene	6,040	4,740	1,550
Toluene	11,720	8,630	3,110
Ethylbenzene	2,250	2,000	600
m/p-Xylenes	4,610	4,200	1,510
o-Xylene	1,930	1,780	770
4-Ethyltoluene	1,510	1,510	660
1,2,4-Trimethylbenzene	1,880	1,740	-
1,3,5-Trimethylbenzene	380	400	-
Phosgene	-	-	50
Peroxyacetyl nitrate	4,977	779	356
Peroxypropionyl nitrate	722	93	149

[†] See Reference 4.

TABLE B-9. SUMMARY OF CURRENT STANDARDS FOR SUBSTANCES MONITORED IN LOVE CANAL AIR SAMPLES

Substance	OSHA[†] Environmental Standards	NIOSH[‡] Recommended Limit	ACGIH[*] Adopted Value	NIOSH Considered Health Effect
Benzene	10ppm, 8 hr. TWA (30 mg/m^3)	1ppm ceiling (3.2 mg/m^3) (60-minute)	30 mg/m^3, TLV-TWA	blood changes, including leukemia
Carbon tetrachloride	10ppm, 8 hr. TWA (65 mg/m^3)	2ppm ceiling (12.6 mg/m) (60-minute)	65 mg/m^3, TLV-TWA	liver cancer
Chlorobenzene	75ppm, 8 hr. TWA	--	350 mg/m^3, TLV-TWA	--
o-Chlorotoluene	--	--	250 mg/m^3, TLV-TWA	--
p-Chlorotoluene	--	--	--	--
1,2-Dibromoethane	20ppm, 8 hr. TWA (152 mg/m^3)	0.13ppm ceiling (1 mg/m^3) (15-minute)	no exposure	damage to skin, eyes, heart, liver, spleen, respiratory and central nervous systems; potential for cancer and mutagenesis
o-Dichlorobenzene	50ppm, ceiling (300 mg/m^3)	--	300 mg/m^3 ceiling	--
p-Dichlorobenzene	75ppm, 8 hr. TWA (450 mg/m^3)	--	450 mg/m^3 TLV-TWA	--
1,1,2,2-Tetrachloroethylene	100ppm, 8 hr. TWA (678 mg/m^3)	50ppm, 10 hr. TWA (339 mg/m^3)	670 mg/m^3 TLV-TWA	nervous system, heart, respiratory, liver
Toluene	200ppm, 8 hr. TWA (750 mg/m^3)	100ppm, 10 hr. TWA (375 mg/m^3)	375 mg/m^3 TLV-TWA	central nervous system depressant

(continued)

TABLE B-9 (continued)

Substance	OSHA[†] Environmental Standards	NIOSH[‡] Recommended Limit	ACGIH[*] Adopted Value	NIOSH Considered Health Effect
γ-BHC (Lindane)	--	--	0.5 mg/m^3 TLV-TWA	--
Hexachlorobenzene	--	--	--	--
Hexachlorocyclopentadiene (C-56)	--	--	0.1 mg/m^3 TLV-TWA	--
1,2,3,4-Tetrachlorobenzene	--	--	--	--
1,2,3-Trichlorobenzene	--	--	--	--
1,2,4-Trichlorobenzene	--	--	40 mg/m^3 TLV-TWA	--
1,3,5-Trichlorobenzene	--	--	--	--
2,4,5-Trichlorophenol	--	--	--	--
Pentachlorobenzene	--	--	--	--
Antimony	0.5 mg/m^3, 8 hr. TWA	0.5 mg/m^3, 10 hr. TWA	0.5 mg/m^3 TLV-TWA	irritation; heart and lung effects
Arsenic	0.01 mg/m^3, 8 hr. TWA	0.002 mg/m^3 ceiling (15-minute)	0.2 mg/m^3 TLV-TWA	dermatitis, lung and lymphatic cancer
Beryllium	0.002 mg/m^3, 8 hr. TWA	0.0005 mg/m^3 (130-minute)	0.002 mg/m^3 TLV-TWA	lung cancer
Cadmium	0.1 mg/m^3, 8 hr. TWA	0.04 mg/m^3, 10 hr. TWA	0.05 mg/m^3, TLV-TWA	lung and kidney effects

(continued)

TABLE B-9 (continued)

Substance	OSHA[†] Environmental Standards	NIOSH[‡] Recommended Limit	ACGIH[*] Adopted Value	NIOSH Considered Health Effect
Copper	--	--	1 mg/m^3 TLV-TWA	--
Lead	0.05 mg/m^3, 8 hr. TWA	0.1 mg/m^3, 10 hr. TWA	0.15 mg/m^3 TLV-TWA	kidney, blood, and nervous system effects
Nickel	1 mg/m^3, 8 hr. TWA	0.015 mg/m^3, 10 hr. TWA	1 mg/m^3 TLV-TWA	skin effects; nasal cancer
Zinc	--	--	--	--

[†] U.S. Occupational Safety and Health Administration (OSHA) environmental standards as of March 1, 1981. The phrase "8 hr. TWA" means the time-weighted average concentration, for a normal 8-hour workday or 40-hour workweek, to which nearly all workers may be exposed without adverse effect; the phrase "ceiling" means the concentration maximum to which workers may be exposed.

[‡] The National Institute of Occupational Safety and Health (NIOSH) recommended work-place exposure limits as of March 1, 1981. Values are reported as "ceiling" or time-weight average; the health effects considered in the establishment of the limit are also listed in the table.

[*] The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLV) for chemical substances in workroom air adopted for 1980. Threshold limit values "refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness." Values are reported as "ceiling" or time-weighted average.

Note: Values reported are in parts per million (ppm) and milligrams per cubic meter (mg/m^3). To convert from milligrams to micrograms, use 1 mg = 1,000 μg.

TABLE B-10. ANALYTICAL RESULTS OF CHLOROFORM, BROMOFORM, BROMODICHLOROMETHANE, AND DIBROMOCHLOROMETHANE, AND TOTAL TRIHALOMETHANES IN WATER SUPPLIES FROM NORS AND NOMS†
(Concentrations in milligrams per liter, ppm)

Compound		NORS	NOMS			
			Phase I	Phase II	Phase III	
					Dechlorinated	Terminal
Chloroform:	Median	0.021	0.027	0.059	0.022	0.044
	Mean	--	0.043	0.083	0.035	0.069
	Range	NF-0.311	NF-0.271	NF-0.47	NF-0.20	NF-0.540
Bromoform:	Median	0.005	LD	LD	LD	LD
	Mean	--	0.003	0.004	0.002	0.004
	Range	NF-0.092	NF-0.039	NF-0.280	NF-0.137	NF-0.190
Dibromochloromethane:	Median	0.001	LD	0.004	0.002	0.003
	Mean	--	0.008	0.012	0.006	0.011
	Range	NF-0.100	NF-0.19	NF-0.290	NF-0.114	NF-0.250
Bromodichloromethane:	Median	0.006	0.010	0.014	0.006	0.011
	Mean	--	0.018	0.018	0.009	0.017
	Range	NF-0.116	NF-0.183	NF-0.180	NF-0.072	NF-0.125
Total Trihalomethanes:	Median	0.027	0.045	0.087	0.037	0.074
	Mean	0.067	0.068	0.117	0.053	0.100
	Range	NF-0.482	NF-0.457	NF-0.784	NF-0.295	NF-0.695

NF: Not Found
LD: Less than Detection Limit

†The National Organics Reconnaissance Survey of Halogenated Organics (NORS) involved 80 U.S. cities. The National Organics Monitoring Survey (NOMS) involved 113 public water systems. Phase I of NOMS is comparable to NORS. Phase II analyses were performed after THM-producing reactions were allowed to run to completion. Phase III analyses were conducted on both dechlorinated samples and on samples that were allowed to run to completion (terminal).

TABLE B-11. EPA NATIONAL DRINKING WATER REGULATIONS

National Interim Primary Drinking Water Regulations[†] (milligrams per liter, ppm)		Recommended National Secondary Drinking Water Regulations[‡] (milligrams per liter, ppm)	
Inorganics	Maximum Contaminant Level	Inorganics	Maximum Contaminant Level
Arsenic	0.05	Chloride	250.0
Barium	1.0	Copper	1.0
Cadmium	0.01	Iron	0.3
Chromium	0.05	Manganese	0.05
Lead	0.05	Sulfate	250.0
Mercury	0.002	Zinc	5.0
Nitrate (as N)	10.0	Total Dissolved Solids	500.0
Selenium	0.01		
Silver	0.05		
Fluoride	1.4 - 2.4[*]		
Organics			
Edrin	0.0002		
γ-BHC (Lindane)	0.004		
Methoxychlor	0.1		
Toxaphene	0.005		
2,4-Dichlorophenoxy-acetic acid (2,4-D)	0.1		
2,4,5-Trichlorophenoxy-propionic acid (2,4,5-TP Silvex)	0.01		
Total Trihalomethanes	0.1		

[†] As published in the Federal Register, Vol. 40, No. 248, December 24, 1975, 59566, and subsequently amended

[‡] Selected contaminants reported from: National Secondary Drinking Water Regulations, EPA-570/9-76-000, July, 1979

[*] The fluoride standard varies according to the annual average maximum daily air temperature for the location in which the community water system is situated.

Note: Total trihalomethanes is the sum of chloroform, dibromochloromethane, bromodichloromethane, and bromoform rounded to two significant figures.

The following information has been extracted from an article published by EPA in the Federal Register, Vol. 45, No. 231. November 28, 1980. The material has been provided here to summarize current EPA water quality criteria.

SUMMARY OF WATER QUALITY CRITERIA

Acenaphthene

Freshwater Aquatic Life

The available data for acenaphthene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,700 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of acenaphthene to sensitive freshwater aquatic animals but toxicity to freshwater algae occur at concentrations as low as 520 μg/l.

Saltwater Aquatic Life

The available data for acenaphthene indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 970 and 710 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to algae occurs at concentrations as low as 500 μg/l.

Human Health

Sufficient data is not available for acenaphthene to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 20 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Acrolein

Freshwater Aquatic Life

The available data for acrolein indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 68 and 21 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for acrolein indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 55 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of acrolein to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of acrolein ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 320 μg/l.

For the protection of human health from the toxic properties of acrolein ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 780 μg/l.

Acrylonitrile

Freshwater Aquatic Life

The available data for acrylonitrile indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 7,550 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of acrylonitrile to sensitive freshwater aquatic life but mortality occurs at concentrations as low as 2,600 μg/l with a fish species exposed for 30 days.

Saltwater Aquatic Life

Only one saltwater species has been tested with acrylonitrile and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of acrylonitrile through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .58 μg/l, .058 μg/l and .006 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 6.5 μg/l, .65 μg/l, and .065 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Aldrin-Dieldrin

Dieldrin

Freshwater Aquatic Life

For dieldrin the criterion to protect fresh water aquatic life as derived using the Guidelines is 0.0019 μg/l as a 24-hour average and the concentration should not exceed 2.5 μg/l at any time.

Saltwater Aquatic Life

For dieldrin the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0019 μg/l as a 24-hour average and the concentration should not exceed 0.71 μg/l at any time.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of dieldrin through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .71 ng/l, .071 ng/l, and .0071 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are .76 ng/l, .076 ng/l, and .0076 ng/l respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Aldrin

Freshwater Aquatic Life

For freshwater aquatic life the concentration of aldrin should not exceed 3.0 μg/l at any time. No data are available concerning the chronic toxicity of aldrin to sensitive freshwater aquatic life.

Saltwater Aquatic Life

For saltwater aquatic life the concentration of aldrin should not exceed 1.3 μg/l at any time. No data are available concerning the chronic toxicity of aldrin to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of aldrin through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .74 ng/1, .074 ng/1, and .0074 ng/1, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are .79 ng/1, .079 ng/1, and .0079 ng/1, respectively. Other concentrations respresenting different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Antimony

Freshwater Aquatic Life

The available data for antimony indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 9,000 and 1,600 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to algae occurs at concentrations as low as 610 µg/l.

Saltwater Aquatic Life

No saltwater organisms have been adequately tested with antimony, and no statement can be made concerning acute or chronic toxicity.

Human Health

For the protection of human health from the toxic properties of antimony ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 146 µg/l.

For the protection of human health from the toxic properties of antimony ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 45,000 µg/l.

Arsenic

Freshwater Aquatic Life

For freshwater aquatic life the concentration of total recoverable trivalent inorganic arsenic should not exceed 440 µg/l at any time. Short-term effects on embryos and larvae of aquatic vertebrate species have been shown to occur at concentrations as low as 40 µg/l.

Saltwater Aquatic Life

The available data for total recoverable trivalent inorganic arsenic indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 508 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trivalent inorganic arsenic to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of arsenic through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 22 ng/l, 2.2 ng/l, and .22 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 175 ng/l, 17.5 ng/l, and 1.75 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Asbestos

Freshwater Aquatic Life

No freshwater organisms have been tested with any asbestiform mineral and no statement can be made concerning acute or chronic toxicity.

Saltwater Aquatic Life

No saltwater organisms have been tested with any asbestiform mineral and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of asbestos through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 300,000 fibers/1,30,000 fibers/1, and 3,000 fibers/1, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Benzene

Freshwater Aquatic Life

The available data for benzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 5,300 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of benzene to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for benzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 5,100 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of benzene to sensitive saltwater aquatic life, but adverse effects occur at concentrations as low as 700 µg/l with a fish species exposed for 168 days.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of benzene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 6.6 µg/l, .66 µg/l, and .066 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 400 µg/l, 40.0 µg/l, and 4.0 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Benzidine

Freshwater Aquatic Life

The available data for benzidine indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 2,500 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of benzidine to sensitive freshwater aquatic life.

Saltwater Aquatic Life

No saltwater organisms have been tested with benzidine and no statement can be made concerning acute and chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of benzidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 1.2 ng/1, .12 ng/1, and .01 ng/1, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5.3 ng/1, .53 ng/1, and .05 ng/1, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Beryllium

Freshwater Aquatic Life

The available data for beryllium indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 130 and 5.3 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Hardness has a substantial effect on acute toxicity.

Salt water Aquatic Life

The limited saltwater data base available for beryllium does not permit any statement concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of beryllium through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 37 ng/l, 3.7 ng/l, and .37 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 641 ng/l, 64.1 ng/l, and 6.41 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Cadmium

Freshwater Aquatic Life

For total recoverable cadmium the criterion (in μg/l) to protect freshwater aquatic life as derived using the Guidelines is the numerical value given by $e^{(1.05[\ln(\text{hardness})]-8.53)}$ as a 24-hour average and the concentration (in μg/l) should not exceed the numerical value given by $e^{(1.05[\ln(\text{hardness})]-3.73)}$ at any time. For example, a hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the criteria are 0.012, 0.025, and 0.051 μg/l, respectively, and the concentration of total recoverable cadmium should not exceed 1.5, 3.0 and 6.3 μg/l, respectively, at any time.

Saltwater Aquatic Life

For total recoverable cadmium the criterion to protect saltwater aquatic life as derived using the Guidelines is 4.5 μg/l as a 24-hour average and the concentration should not exceed 59 μg/l at any time.

Human Health

The ambient water quality criterion for cadmium is recommended to be identical to the existing drinking water standard which is 10 μg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Carbon Tetrachloride

Freshwater Aquatic Life

The available date for carbon tetrachloride indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 35,200 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of carbon tetrachloride to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for carbon tetrachloride indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 50,000 μg/l and would occur at lower concentrations among species that are more sensitive that those tested. No data are available concerning the chronic toxicity of carbon tetrachloride to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of carbon tetrachloride through ingestion of contaminated water and contaminated aquatic organisms the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 4.0μg/l, .40 μg/l, and .04 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 69.4 μg/l, 6.94 μg/l, and .69 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Chlordane

Freshwater Aquatic Life

For chlordane the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0043 μg/l as a 24-hour average and the concentration should not exceed 2.4 μg/l at any time.

Saltwater Aquatic Life

For chlordane the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0040 μg/l as a 24-hour average and the concentration should not exceed 0.09 μg/l at any time.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of chlordane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 4.6 ng/l, .46 ng/l, and .046 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 4.8 ng/l, .48 ng/l, and .048 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Chlorinated Benzenes

Freshwater Aquatic Life

The available data for chlorinated benzenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 250 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of the more toxic of the chlorinated benzenes to sensitive freshwater aquatic life but toxicity occurs at concentrations as low as 50 µg/l for a fish species exposed for 7.5 days.

Saltwater Aquatic Life

The available data for chlorinated benzenes indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 160 and 129 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of hexachlorobenzene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding recommended criteria are 7.2 ng/l, .72 ng/l, and .072 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 7.4 ng/l, .74 ng/l, and .074 ng/l, respectively.

For the protection of human health from the toxic properties of 1,2,4,5-tetrachlorobenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 38 µg/l.

For the protection of human health from the toxic properties of 1,2,4,5-tetrachlorobenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 48 µg/l.

For the protection of human health from the toxic properties of pentachlorobenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 74 µg/l.

For the protection of human health from the toxic properties of pentachlorobenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 85 µg/l.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for trichlorobenzene.

For comparison purposes, two approaches were used to derive criterion levels for monochlorobenzene. Based on available toxicity data, for the protection of public health, the derived level is 488 µg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 20 µg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Chlorinated Ethanes

Freshwater Aquatic Life

The available freshwater data for chlorinated ethanes indicate that toxicity increases greatly with increasing chlorination, and that acute toxicity occurs at concentrations as low as 118,000 µg/l for 1,2-dichloroethane, 18,000 µg/l for two trichloroethanes, 9,320 µg/l for two tetrachloroethanes, 7,240 µg/l for pentachloroethane, and 980 µg/l for hexachloroethane. Chronic toxicity occurs at concentrations as low as 20,000 µg/l for 1,2-dichloroethane, 9,400 µg/l for 1,1,2-trichloroethane, 2,400 µg/l for 1,1,2,2,-tetrachloroethane, 1,100 µg/l for pentachloroethane, and 540 µg/l for hexachloroethane. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available saltwater data for chlorinated ethanes indicate that toxicity increases greatly with increasing chlorination and that acute toxicity to fish and invertebrate species occurs at concentrations as low as 113,000 µg/l for 1,2-dichloroethane, 31,200 µg/l for 1,1,1-trichloroethane, 9,020 µg/l for 1,1,2,2-tetrachloroethane, 390 µg/l for pentachloroethane, and 940 µg/l for hexachloroethane. Chronic toxicity occurs at concentrations as low as 281 µg/l for pentachloroethane. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 1,2-dichloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 9.4 µg/l, .94 µg/l, and .094 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 2,430 µg/l, 243 µg/l, and 24.3 µg/l respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the protection of human health from the toxic properties of 1,1,1-trichloroethane ingested through water and contaminated aquatic organism, the ambient water criterion is determined to be 18.4 mg/l.

For the protection of human health from the toxic properties of 1,1,1,-trichloroethane ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 1.03 g/l.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 1,1,2-trichloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 6.0 μg/l, .6 μg/l, and .06 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 418 μg/l, 41.8 μg/l, and 4.18 μg/l respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 1,1,2,2-tetrachloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 1.7 μg/l, .17 μg/l, and .017 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 107 μg/l, 10.7 μg/l, and 1.07 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of hexachloroethane through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 19 μg/l, 1.9 μg/l, and .19 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 87.4 μg/l, 8.74 μg/l, and .87 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for monochloroethane.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for 1,1,-dichloroethane.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for 1,1,1,2-tetrachloroethane.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for pentachloroethane.

Chlorinated Naphthalenes

Freshwater Aquatic Life

The available data for chlorinated naphthalenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,600 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for chlorinated napthalenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.5 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated naphthalenes to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for chlorinated napthalenes.

Chlorinated Phenols

Freshwater Aquatic Life

The available freshwater data for chlorinated phenols indicate that toxicity generally increases with increasing chlorination, and that acute toxicity occurs at concentrations as low as 30 μg/l for 4-chloro-3-methylphenol to greater than 500,000 μg/l for other compounds. Chronic toxicity occurs at concentrations as low as 970 μg/l for 2,4,6-trichlorophenol. Acute and chronic toxicity would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available saltwater data for chlorinated phenols indicate that toxicity generally increases with increasing chlorination and that acute toxicity occurs at concentrations as low as 440 μg/l for 2,3,5,6-tetrachlorophenol and 29,700 μg/l for 4-chlorophenol. Acute toxicity would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of chlorinated phenols to sensitive saltwater aquatic life.

Human Health

Sufficient data is not available for 3-monochlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 0.1 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 4-monochlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 0.1 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 2,3-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is .04 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 2,5-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is .5 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 2,6-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is .2 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 3,4-dichlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is .3 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 2,3,4,6-tetrachlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

For comparison purposes, two approaches were used to derive criterion levels for 2,4,5-trichlorophenol. Based on available toxicity data, for the protection of public health, the derived level is 2.6 mg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1.0 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 2,4,6-trichlorophenol through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 12 μg/l, 1.2 μg/l, and .12 μg/l respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 36 μg/l, 3.6 μg/l, and .36 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 2 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 2-methyl-4-chlorophenol to derive a level which would protect against any potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1800 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 3-methyl-4-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 3000 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Sufficient data is not available for 3-methyl-6-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 20 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Chloroalkyl Ethers

Freshwater Aquatic Life

The available data for chloroalkyl ethers indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 238,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of chloroalkyl ethers to sensitive freshwater aquatic life.

Saltwater Aquatic Life

No saltwater organisms have been tested with any chloroalkyl ether and no statement can be made concerning acute and chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of bis-(chloromethyl)-ether through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .038 ng/l, .0038 ng/l, and .00038 ng/l, respectively.

If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 18.4 ng/l, 1.84 ng/l, and .184 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of bis (2-chloroethyl) ether through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .3 μg/l, .03 μg/l, and .003 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 13.6 μg/l, 1.36 μg/l, and .136 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the protection of human health from the toxic properties of bis (2-chloroisopropyl) ether ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 34.7 μg/l.

For the protection of human health from the toxic properties of bis (2-chloroisopropyl) ether ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 4.36 mg/l.

Chloroform

Freshwater Aquatic Life

The available data for choloroform indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 28,900 μg/l, and would occur at lower concentrations among species that are more sensitive than the three tested species. Twenty-seven-day LC50 values indicate that chronic toxicity occurs at concentrations as low as 1,240 μg/l, and could occur at lower concentrations among species or other life stages that are more sensitive than the earliest life cycle stage of the rainbow trout.

Saltwater Aquatic Life

The data base for saltwater species is limited to one test and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of chloroform through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 1.90 μg/l, .19 μg/l, and .019 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 157 μg/l, 15.7 μg/l, and 1.57 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

2-Chlorophenol

Freshwater Aquatic Life

The availabe data for 2-chlorophenol indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 4,380 μg/l and would occur at lower concentrations among species that are more sensitive that those tested. No definitive data are available concerning the chronic toxicity of 2-chlorophenol to sensitive freshwater aquatic life but flavor impairment occurs in one species of fish at concentrations as low as 2,000 μg/l.

Saltwater Aquatic Life

No saltwater organisms have been tested with 2-chlorophenol and no statement can be made concerning acute and chronic toxicity.

Human Health

Sufficient data is not available for 2-chlorophenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 0.1 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Chromium

Freshwater Aquatic Life

For total recoverable hexavalent chromium the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.29 μg/l as a 24-hour average and the concentration should not exceed 21 μg/l at any time.

For freshwater aquatic life the concentration (in μg/l) of total recoverable trivalent chromium should not exceed the numerical value given by "e(1.08[ln(hardness)]+3.48)" at any time. For example, at hardnesses of 50, 100 and 200 mg/l as $CaCO_3$ the concentration of total recoverable trivalent chromium should not exceed 2,200, 4,700, and 9,900 μg/l, respectively, at any time. The available data indicate that chronic toxicity to freshwater aquatic life occurs at concentrations as low a 44 μg/l and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

For total recoverable hexavalent chromium the criterion to protect saltwater aquatic life as derived using the Guidelines is 18 μg/l as a 24-hour average and the concentration should not exceed 1,260 μg/l at any time.

For total recoverable trivalent chromium, the availabe data indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 10,300 μg/l, and would occur at lower concentrations amoung species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trivalent chromium to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of Chromium III ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 170 mg/l.

For the protection of human health from the toxic properties of Chromium III ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 3433 mg/l.

The ambient water quality criterion for total Chromium VI is recommended to be identical to the existing drinking water standard which is 50 μg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Copper

Freshwater Aquatic Life

For total recoverable copper the criterion to protect freshwater aquatic life as derived using the Guidelines is 5.6 μg/l as a 24-hour average and the concentration (in μg/l) should not exceed the numerical value given by e(0.94[ln(hardness)]-1.23) at any time. For example, at hardnesses of 50, 100, and 200 mg/l $CaCO_3$ the concentration of total recoverable copper should not exceed 12, 22, and 43 μg/l at any time.

Saltwater Aquatic Life

For total recoverable copper the

criterion to protect saltwater aquatic life as derived using the Guidelines is 4.0 µg/l as a 24-hour average and the concentration should not exceed 23 µg/l at any time.

Human Health

Sufficient data is not available for copper to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1 mg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Cyanide

Freshwater Aquatic Life

For free cyanide (sum of cyanide present as HCN and CN^-, expressed as CN) the criterion to protect freshwater aquatic life as derived using the Guidelines is 3.5 µg/l as a 24-hour average and the concentration should not exceed 52 µg/l at any time.

Saltwater Aquatic Life

The available data for free cyanide (sum of cyanide present as HCN and CN^-, expressed as CN) indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 30 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. If the acute-chronic ratio for saltwater organisms is similar to that for freshwater organisms, chronic toxicity would occur at concentrations as low as 2.0 µg/l for the tested species and at lower concentrations among species that are more sensitive than those tested.

Human Health

The ambient water quality criterion for cyanide is recommended to be identical to the existing drinking water standard which is 200 µg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

DDT and Metabolites

Freshwater Aquatic Life

DDT

For DDT and its metabolites the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0010 µg/l as a 24-hour average and the concentration should not exceed 1.1 µg/l at any time.

TDE

The available data for TDE indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 0.6 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of TDE to sensitive freshwater aquatic life.

DDE

The available data for DDE indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 1,050 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of DDE to sensitive freshwater aquatic life.

Saltwater Aquatic Life

DDT

For DDT and its metabolites the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0010 µg/l as a 24-hour average and the concentration should not exceed 0.13 µg/l at any time.

TDE

The available data for TDE indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 3.6 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of TDE to sensitive saltwater aquatic life.

DDE

The available data for DDE indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 14 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of DDE to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of DDT through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .24 ng/l, .024 ng/l, and .0024 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are .24 ng/l, .024 ng/l, and .0024 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment of an "acceptable" risk level.

Dichlorobenzenes

Freshwater Aquatic Life

The available data for dichlorobenzenes indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 1,120 and 763 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for dichlorobenzenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 1,970 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dichlorobenzenes to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of dichlorobenzenes (all isomers) ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 400 µg/l.

For the protection of human health from the toxic properties of dichlorobenzenes (all isomers) ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 2.6 mg/l.

Dichlorobenzidines

Freshwater Aquatic Life

The data base available for dichlorobenzidines and freshwater organisms is limited to one test on bioconcentration of 3,3'-dichlorobenzidine and no statement can be made concerning acute or chronic toxicity.

Saltwater Aquatic Life

No saltwater organisms have been tested with any dichlorobenzidine and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of dichlorobenzidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero base on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .103 μg/l, .0103 μg/l, and .00103 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are .204 μg/l, .0204 μg/l, and .00204 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Dichloroethylenes

Freshwater Aquatic Life

The available data for dichloroethylenes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 11,600 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of dichlorethylenes to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for dichlorethylenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 224,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity dichloroethylenes to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 1,1-dichloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .33 μg/l, .033 μg/l, and .0033 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 18.5 μg/l, 1.85 μg/l, and .185 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficency in the available data for 1,2-dichloroethylene.

2,4-Dichlorophenol

Freshwater Aquatic Life

The available data for 2,4-dichlorophenol indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 2,020 and 365 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive that those tested. Mortality to early life stages of one species of fish occurs at concentrations as low as 70 μg/l.

Saltwater Aquatic Life

Only one test has been conducted with saltwater organisms on 2,4-dichlorophenol and no statement can be made concerning acute or chronic toxicity.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for 2,4-dichlorophenol. Based on available toxicity data, for the protection of public health, the derived level is 3.09 mg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 0.3 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Dichloropropanes/Dichloropropenes

Freshwater Aquatic Life

The available data for dichloropropanes indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 23,000 and 5,700 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichloropropenes indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 6,060 and 244 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for dichloropropanes indicate that acute and chronic toxicity to saltwater aquatic life occurs at concentrations as low as 10,300 and 3,040 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

The available data for dichloropropenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low a as 790 μg/l, and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dichloropropenes to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for dichloropropanes.

For the protection of human health from the toxic properties of dichloropropenes ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 87 μg/l.

For the protection of human health from the toxic properties of dichloropropenes ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 14.1 mg/l.

2,4-Dimethylphenol

Freshwater Aquatic Life

The available data for 2,4-dimethylphenol indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 2,120 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of dimethylphenol to sensitive freshwater aquatic life.

Saltwater Aquatic Life

No saltwater organisms have been tested with 2,4-dimethylphenol and no statement can be made concerning acute and chronic toxicity.

Human Health

Sufficient data are not available for 2,4-dimethylphenol to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undersirable taste and odor quality of ambient water, the estimated level is 400 µg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

2,4-Dinitrotoluene

Freshwater Aquatic Life

The available data for 2,4-dinitrotoluene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 330 and 230 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for 2,4-dinitrotoluenes indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 590 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of 2,4-dinitrotoluenes to sensitive saltwater aquatic life but a decrease in algal cell numbers occurs at concentrations as low as 370 µg/l.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 2,4-dinitrotoluene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 1.1 µg/l, 0.11 µg/l, and 0.011 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 91 µg/l, 9.1 µg/l, and 0.91 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

1,2-Diphenylhydrazine

Freshwater Aquatic Life

The available data for 1,2-diphenylhydrazine indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 270 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of 1,2-diphenylhydrazine to sensitive freshwater aquatic life.

Saltwater Aquatic Life

No saltwater organisms have been tested with 1,2-diphenylhydrazine and no statement can be made concerning acute and chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of 1,2-diphenylhydrazine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 422 ng/l, 42 ng/l, and 4 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5.6 µg/l, 0.56 µg/l, and 0.056 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Endosulfan

Freshwater Aquatic Life

For endosulfan the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.056 µg/l as a 24-hour average and the concentration should not exceed 0.22 µg/l at any time.

Saltwater Aquatic Life

For endosulfan the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0087 µg/l as a 24-hour average and the concentration should not exceed 0.034 µg/l at any time.

Human Health

For the protection of human health from the toxic properties of endosulfan ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 74 µg/l.

For the protection of human health from the toxic properties of endosulfan ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 159 µg/l.

Endrin

Freshwater Aquatic Life

For endrin the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0023 µg/l as a 24-hour average and the concentration should not exceed 0.18 µg/l at any time.

Saltwater Aquatic Life

For endrin the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0023 µg/l as a 24-hour average and the concentration should not exceed 0.037 µg/l at any time.

Human Health

The ambient water quality criterion for endrin is recommended to be identical to the existing drinking water standard which is 1 µg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Ethylbenzene

Freshwater Aquatic Life

The available data for ethylbenzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 32,000 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of ethylbenzene to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for ethylbenzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 430 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of ethylbenzene to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of ethylbenzene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 1.4 mg/l.

For the protection of human health from the toxic properties of ethylbenzene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 3.28 mg/l.

Fluoranthene

Freshwater Aquatic Life

The available data for fluoranthene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 3980 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of fluoranthene to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for fluoranthene indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 40 and 16 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the protection of human health from the toxic properties of fluoranthene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 42 µg/l.

For the protection of human health from the toxic properties of fluoranthene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 54 µg/l.

Haloethers

Freshwater Aquatic Life

The available data for haloethers indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 360 and 122 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

No saltwater organisms have been tested with any haloether and no statement can be made concerning acute or chronic toxicity.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for haloethers.

Halomethanes

Freshwater Aquatic Life

The available data for halomethanes indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 11,000 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of halomethanes to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for halomethanes indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 12,000 and 6,400 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. A decrease in algal cell numbers occurs at concentrations as low as 11,500 µg/l.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of chloromethane, bromomethane, dichloromethane, bromodichloromethane, tribromomethane, dichlorodifluoromethane, trichlorofluoromethane, or combinations of these chemicals through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 1.9 µg/l, 0.19 µg/l, and 0.019 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 157 µg/l, 15.7 µg/l, and 1.57 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Heptachlor

Freshwater Aquatic Life

For heptachlor the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.0038 µg/l as a 24-hour average and the concentration should not exceed 0.52 µg/l at any time.

Saltwater Aquatic Life

For heptachlor the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.0036 µg/l as a 24-hour average and the concentration should not exceed 0.053 µg/l at any time.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of heptachlor through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 2.78 ng/l, .28 ng/l, and .028 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 2.85 ng/l, .29 ng/l, and .029 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Hexachlorobutadiene

Freshwater Aquatic Life

The available data for hexachlorobutadiene indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 90 and 9.3 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for hexachlorobutadiene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 32 µg/l and would occur at lower concentrations among species that are more sensitive that those tested. No data are available concerning the chronic toxicity of hexachlorobutadiene to sensitive saltwater aquatic life

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of hexachlorobutadiene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 4.47 μg/l, 0.45 μg/l, and 0.045 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 500 μg/l, 50 μg/l, and 5 μg/l respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Hexachlorocyclohexane

Lindane

Freshwater Aquatic Life

For Lindane the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.080 μg/l as a 24-hour average and the concentration should not exceed 2.0 μg/l at any time.

Saltwater Aquatic Life

For saltwater aquatic life the concentration of lindane should not exceed 0.16 μg/l at any time. No data are available concerning the chronic toxicity of lindane to sensitive saltwater aquatic life.

BHC

Freshwater Aquatic Life

The available date for a mixture of isomers of BHC indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 100 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of a mixture of isomers of BHC to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available date for a mixture of isomers of BHC indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 0.34 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of a mixture of isomers of BHC to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of alpha-HCH through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 92 ng/l, 9.2 ng/l, and .92 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 310 ng/l, 31.0 ng/l, and 3.1 ng/l respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of beta-HCH through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 163 ng/l, 16.3 ng/l, and 1.63 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 547 ng/l, 54.7 ng/l, and 5.47 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of tech-HCH through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 123 ng/l, 12.3 ng/l, and 1.23 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 414 ng/l, 41.4 ng/l, and 4.14 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of gamma-HCH through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 186 ng/l, 18.6 ng/l, and 1.86 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 625 ng/l, 62.5 ng/l, 6.25 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for delta-HCH.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for epsilon-HCH.

Hexachlorocyclopentadiene

Freshwater Aquatic Life

The available data for hexachlorocyclopentadiene indicate that acute and chronic toxicity to freshwater aquatic life occurs at concentrations as low as 7.0 and 5.2 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data to hexachlorocyclopentadiene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 7.0 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of hexachlorocyclopentadiene to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for hexachlorocyclopentadiene. Based on available toxicity data, for the protection of public health, the derived level is 206 µg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 1.0 µg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Isophorone

Freshwater Aquatic Life

The available data for isophorone indicate that acute toxicity to freshwater aquatic life ocurs at concentrations as low as 117,000 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of isophorone to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for isophorone indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 12,900 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of isophorone to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of isophorone ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 5.2 mg/l.

For the protection of human health from the toxic properties of isophorone ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 520 mg/l.

Lead

Freshwater Aquatic Life

For total recoverable lead the criterion (in µg/l) to protect freshwater aquatic life as derived using the Guidelines is the numerical value given by e(2.35[ln(hardness)]–9.48) as a 24-hour average and the concentration (in µg/l) should not exceed the numerical value given by e(1.22[ln(hardness)]–0.47) at any time. For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the criteria are 0.75, 3.8, and 20 µg/l, respectively, as 24-hour averages, and the concentrations should not exceed 74, 170, and 400 µg/l, respectively, at any time.

Saltwater Aquatic Life

The available data for total recoverable lead indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 668 and 25 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

The ambient water quality criterion for lead is recommended to be identical to the existing drinking water standard which is 50 µg/l. Analysis of the toxic effects data resulted in a calculated level which is protective to human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Mercury

Freshwater Aquatic Life

For total recoverable mercury the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.00057 µg/l as a 24-hour average and the concentration should not exceed 0.0017 µg/l at any time.

Saltwater Aquatic Life

For total recoverable mercury the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.025 µg/l as a 24-hour average and the concentration should not exceed 3.7 µg/l at any time.

Human Health

For the protection of human health from the toxic properties of mercury ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 144 ng/l.

For the protection of human health from the toxic properties of mercury ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 146 ng/l.

Note.—These values include the consumption of freshwater, estuarine, and marine species.

Naphthalene

Freshwater Aquatic Life

The available data to naphthalene indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 2,300 and 620 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for naphthalene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,350 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of naphthalene to sensitive saltwater aquatic life.

Human Health

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for naphthalene.

Nickel

Freshwater Aquatic Life

For total recoverable nickel the criterion (in µg/l) to protect freshwater aquatic life as derived using the Guidelines is the numerical value given by e(0.76 [ln (hardness)] +1.06) as a 24-hour average and the concentration (in µg/l) should not exceed the numerical value given by e(0.76[ln (hardness)] + 1.02) at any time. For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the criteria are 56, 96, and 160 µg/l, respectively, as 24-hour averages, and the concentrations should not exceed 1,100, 1,800, and 3,100 µg/l, respectively, at any time.

Saltwater Aquatic Life

For total recoverable nickel the criterion to protect saltwater aquatic life as derived using the Guidelines is 7.1 µg/l as a 24-hour average and the concentration should not exceed 140 µg/l at any time.

Human Health

For the protection of human health from the toxic properties of nickel ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 13.4 µg/l.

For the protection of human health from the toxic properties of nickel ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 100 µg/l.

Nitrobenzene

Freshwater Aquatic Life

The available data for nitrobenzene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 27,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No definitive data are available concerning the chronic toxicity of nitrobenzene to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for nitrobenzene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 6,680 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrobenzene to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for nitrobenzene. Based on available toxicity data, for the protection of public health, the derived level is 19.8 mg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 30 μg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have no demonstrated relationship to potential adverse human health effects.

Nitrophenols

Freshwater Aquatic Life

The available data for nitrophenols indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 230 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrophenols to sensitive freshwater aquatic life but toxicity to one species of algae occurs at concentrations as low as 150 μg/l.

Saltwater Aquatic Life

The available data for nitrophenols indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 4,850 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrophenols to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of 2,4-dinitro-o-cresol ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 13.4 μg/l.

For the protection of human health from the toxic properties of 2,4-dinitro-o-cresol ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 765 μg/l.

For the protection of human health from the toxic properties of dinitrophenol ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 70 μg/l.

For the protection of human health from the toxic properties of dinitrophenol ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 14.3 mg/l.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for mononitrophenol.

Using the present guidelines, a satisfactory criterion cannot be derived at this time due to the insufficiency in the available data for tri-nitrophenol.

Nitrosamines

Freshwater Aquatic Life

The available data for nitrosamines indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 5,850 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrosamines to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for nitrosamines indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 3,300,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of nitrosamines to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of n-nitrosodimethylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 14 ng/l, 1.4 ng/l, and .14 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 160,000 ng/l, 16,000 ng/l, and 1,600 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure of n-nitrosodiethylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 8 ng/l, 0.8 ng/l, and 0.08 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 12,400 ng/l, 1,240 ng/l, and 124 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure in n-nitrosodi-n-butylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 64 ng/l 6.4 ng/l and .064 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5,868 ng/l, 587 ng/l, and 58.7 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure in n-nitrosodiphenylamine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 49,000 ng/l 4,900 ng/l and 490 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 161,000 ng/l, 16,100 ng/l, and 1,610 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

For the maximum protection of human health from the potential carcinogenic effects due to exposure in n-nitrosopyrrolidine through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk, over the lifetimes are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 160 ng/l 16.0 ng/l and 1.60 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 919,000 ng/l, 91,900 ng/l, and 9,190 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Pentachlorophenol

Freshwater Aquatic Life

The available data for pentachlorophenol indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 55 and 3.2 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for pentachlorophenol indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 53 and 34 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for pentachlorophenol. Based on available toxicity data, for the protection of public health, the derived level is 1.01 mg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 30 µg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Phenol

Freshwater Aquatic Life

The available data for phenol indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 10,200 and 2,560 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for phenol indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 5,800 ug/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of phenol to sensitive saltwater aquatic life.

Human Health

For comparison purposes, two approaches were used to derive criterion levels for phenol. Based on available toxicity data, for the protection of public health, the derived level is 3.5 mg/l. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 0.3 mg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criterion have limitations and have no demonstrated relationship to potential adverse human health effects.

Phthalate Esters

Freshwater Aquatic Life

The available data for phthalate esters indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 940 and 3 µg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for phthalate esters indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2944 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of phthalate esters to sensitive saltwater aquatic life but toxicity to one species of algae occurs at concentrations as low as 3.4 µg/l.

Human Health

For the protection of human health from the toxic properties of dimethyl-phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 313 mg/l.

For the protection of human health from the toxic properties of dimethyl-phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 2.9 g/l.

For the protection of human health from the toxic properties of diethyl-phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 350 mg/l.

For the protection of human health from the toxic properties of diethyl-phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 1.8 g/l.

For the protection of human health from the toxic properties of dibutyl-phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 34 mg/l.

For the protection of human health from the toxic properties of dibutyl-phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 154 mg/l.

For the protection of human health

from the toxic properties of di-2-ethylhexyl-phthalate ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 15 mg/l.

For the protection of human health from the toxic properties of di-2-ethylhexyl-phthalate ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 50 mg/l.

Polychlorinated Biphenyls

Freshwater Aquatic Life

For polychlorinated biphenyls the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.014 µg/l as a 24-hour average. The available data indicate that acute toxicity to freshwater aquatic life probably will only occur at concentrations above 2.0 µg/l and that the 24-hour average should provide adequate protection against acute toxicity.

Saltwater Aquatic Live

For polychlorinated biphenyls the criterion to protect saltwater aquatic life as derived using the Guidelines is 0.030 µg/l as a 24-hour average. The available data indicate that acute toxicity to saltwater aquatic life probably will only occur at concentrations above 10 µg/l and that the 24-hour average should provide adequate protection against acute toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of PCBs through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are .79 ng/l, 0.79 ng/l, and .0079 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are .79 ng/l, .079 ng/l, and .0079 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Polynuclear Aromatic Hydrocarbons (PAHs)

Freshwater Aquatic Life

The limited freshwater data base available for polynuclear aromatic hydrocarbons, mostly from short-term bioconcentration studies with two compounds, does not permit a statement concerning acute or chronic toxicity.

Saltwater Aquatic Life

The available data for polynuclear aromatic hydrocarbons indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 300 ug/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of polynuclear aromatic hydrocarbons to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of PAHs through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 28 ng/l, 2.8 ng/l, and .28 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 311 ng/l, 31.1 ng/l, and 3.11 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Selenium

Freshwater Aquatic Life

For total recoverable inorganic selenite the criterion to protect freshwater aquatic life as derived using the Guidelines is 35 µg/l as a 24-hour average and the concentration should not exceed 260 µg/l at any time.

The available data for inorganic selenate indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 760 µg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of inorganic selenate to sensitive freshwater aquatic life.

Saltwater Aquatic Life

For total recoverable inorganic selenite the criterion to protect saltwater aquatic life as derived using the Guidelines is 54 µg/l as a 24-hour average and the concentration should not exceed 410 µg/l at any time.

No data are available concerning the toxicity of inorganic selenate to saltwater aquatic life.

Human Health

The ambient water quality criterion for selenium is recommended to be identical to the existing drinking water standard which is 10 µg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard. For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Silver

Freshwater Aquatic Life

For freshwater aquatic life the concentration (in µg/l) of total recoverable silver should not exceed the numerical value given by "e[1.72(ln (hardness)-6.52)]" at any time. For example, at hardnesses of 50, 100, 200 mg/l as $CaCO_3$ the concentration of total recoverable silver should not exceed 1.2, 4.1, and 13 µg/l, respectively, at any time. The available data indicate that chronic toxicity to freshwater aquatic life may occur at concentrations as low as 0.12 µg/l.

Saltwater Aquatic Life

For saltwater aquatic life the concentration of total recoverable silver should not exceed 2.3 µg/l at any time. No data are available concerning the chronic toxicity of silver to sensitive saltwater aquatic life.

Human Health

The ambient water quality criterion for silver is recommended to be identical to the existing drinking water standard which is 50 µg/l. Analysis of the toxic effects data resulted in a calculated level which is protective of human health against the ingestion of contaminated water and contaminated aquatic organisms. The calculated value is comparable to the present standard.

For this reason a selective criterion based on exposure solely from consumption of 6.5 grams of aquatic organisms was not derived.

Tetrachloroethylene

Freshwater Aquatic Life

The available data for tetrachloroethylene indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 5,280 and 840 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Saltwater Aquatic Life

The available data for tetrachloroethylene indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations low as 10,200 and 450 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of tetrachloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 8 μg/l, .8 μg/l, and .08 μg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 88.5 μg/l, 8.85 μg/l, and .88 μg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Thallium

Freshwater Aquatic Life

The available data for thallium indicate that acute and chronic toxicity to freshwater aquatic life occur at concentrations as low as 1,400 and 40 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested. Toxicity to one species of fish occurs at concentrations as low as 20 μg/l after 2,600 hours of exposure.

Saltwater Aquatic Life

The available data for thallium indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,130 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of thallium to sensitive saltwater aquatic life.

Human Health

For the protection of human health from the toxic properties of thallium ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 13 μg/l.

For the protection of human health from the toxic properties of thallium ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 48 μg/l.

Toluene

Freshwater Aquatic Life

The available data for toluene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 17,500 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of toluene to sensitive freshwater aquatic life.

Saltwater Aquatic Life

The available data for toluene indicate that acute and chronic toxicity to saltwater aquatic life occur at concentrations as low as 6,300 and 5,000 μg/l, respectively, and would occur at lower concentrations among species that are more sensitive than those tested.

Human Health

For the protection of human health from the toxic properties of toluene ingested through water and contaminated aquatic organisms, the ambient water criterion is determined to be 14.3 mg/l.

For the protection of human health from the toxic properties of toluene ingested through contaminated aquatic organisms alone, the ambient water criterion is determined to be 424 mg/l.

Toxaphene

Freshwater Aquatic Life

For toxaphene the criterion to protect freshwater aquatic life as derived using the Guidelines is 0.013 μg/l as a 24-hour average and the concentration should not exceed 1.6 μg/l at any time.

Saltwater Aquatic Life

For saltwater aquatic life the concentration of toxaphene should not exceed 0.070 μg/l at any time. No data are available concerning the chronic toxicity of toxaphene to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of toxaphene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 7.1 ng/l, .71 ng/l, and .07 ng/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 7.3 ng/l, .73 ng/l, and .07 ng/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Trichloroethylene

Freshwater Aquatic Life

The available data for trichloroethylene indicate that acute toxicity to freshwater aquatic life occurs at concentrations as low as 45,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trichloroethylene to sensitive freshwater aquatic life but adverse behavioral effects occurs to one species at concentrations as low as 21,900 μg/l.

Saltwater Aquatic Life

The available data for trichloroethylene indicate that acute toxicity to saltwater aquatic life occurs at concentrations as low as 2,000 μg/l and would occur at lower concentrations among species that are more sensitive than those tested. No data are available concerning the chronic toxicity of trichloroethylene to sensitive saltwater aquatic life.

Human Health

For the maximum protection of human

health from the potential carcinogenic effects due to exposure of trichloroethylene through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 27 µg/l, 2.7 µg/l, and .27 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 807 µg/l, 80.7 µg/l, and 8.07 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Vinyl Chloride

Freshwater Aquatic Life

No freshwater organisms have been tested with vinyl chloride and no statement can be made concerning acute or chronic toxicity.

Saltwater Aquatic Life

No saltwater organisms have been tested with vinyl chloride and no statement can be made concerning acute or chronic toxicity.

Human Health

For the maximum protection of human health from the potential carcinogenic effects due to exposure of vinyl chloride through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time. Therefore, the levels which may result in incremental increase of cancer risk over the lifetime are estimated at 10^{-5}, 10^{-6}, and 10^{-7}. The corresponding criteria are 20 µg/l, 2.0 µg/l, and .2 µg/l, respectively. If the above estimates are made for consumption of aquatic organisms only, excluding consumption of water, the levels are 5,246 µg/l, 525 µg/l, and 52.5 µg/l, respectively. Other concentrations representing different risk levels may be calculated by use of the Guidelines. The risk estimate range is presented for information purposes and does not represent an Agency judgment on an "acceptable" risk level.

Zinc

Freshwater Aquatic Life

For total recoverable zinc the criterion to protect freshwater aquatic life as derived using the Guidelines is 47 µg/l as a 24-hour average and the concentration (in µg/l) should not exceed the numerical value given by $e^{(0.83[\ln(\text{hardness})] + 1.95)}$ at any time. For example, at hardnesses of 50, 100, and 200 mg/l as $CaCO_3$ the concentration of total recoverable zinc should not exceed 180, 320, and 570 µg/l at any time.

Saltwater Aquatic Life

For total recoverable zinc the criterion to protect saltwater aquatic life as derived using the Guidelines is 58 µg/l as a 24-hour average and the concentration should not exceed 170 µg/l at any time.

Human Health

Sufficient data is not available for zinc to derive a level which would protect against the potential toxicity of this compound. Using available organoleptic data, for controlling undesirable taste and odor quality of ambient water, the estimated level is 5 mg/l. It should be recognized that organoleptic data as a basis for establishing a water quality criteria have limitations and have not demonstrated relationship to potential adverse human health effects.

APPENDIX C
QUALITY ASSURANCE FOR WATER SAMPLES

OVERVIEW OF QUALITY ASSURANCE PROGRAM

This Appendix summarizes the quality assurance (QA) activities and data validation procedures used for Love Canal water analyses. The initial planning for the Love Canal project included a comprehensive quality assurance effort, perhaps more comprehensive than any previous EPA effort. Details of all of the quality assurance plans developed for the study are presented in a four-part document entitled Quality Assurance Plan, Love Canal Study, LC-1-619-206 that was prepared by the GCA Corporation, the prime contractor for the project, and approved by the EPA quality assurance officers. That document consists of a main volume plus Appendix A on sampling procedures, Appendix B on analytical procedures, and Appendix Q on the subcontractor's QA plans. A more detailed discussion of the results of the prime contractor's and subcontractor's quality assurance efforts is contained in the Love Canal Monitoring Program, GCA QA/QC Summary Report by the GCA Corporation. These documents, which are available through NTIS, should be consulted for more details on the project.

The design of the water monitoring program at Love Canal and the related quality assurance plan was developed by EPA and described in detail in writing to the prime contractor. This written guidance was intended to establish minimum standards for quality assurance, and it was expected that the prime and subcontractors would amplify the requirements in their individual QA plans. During the design, study, and data evaluation phases of the Love Canal project, the plans and results were reviewed by an independent group, the sampling protocols study group of the EPA's Science Advisory Board.

It was the responsibility of the prime contractor to oversee the day-to-day quality assurance programs of the subcontractors using the approved plans and written guidance provided by EPA. This written guidance formed the basis for the GCA Corporation quality assurance plan document mentioned earlier. Briefly, the written quality assurance guidance provided by EPA included the following items:

1. Directives on sample collection, preservation, and holding times

2. Directives on analytical methods

3. Directives on the external quality assurance program including the use of performance evaluation samples and quality control samples provided by EMSL-Cincinnati. The purpose of the external quality assurance program was to give the prime contractor some of the tools necessary to oversee the day-to-day quality assurance program.

4. Directives on the internal quality assurance program including required measurements of gas chromatography/mass spectrometry (GC/MS) reference compounds, method blanks, laboratory control standards, laboratory duplicates, surrogate analytes for EPA analysis methods 624 and 625, and known additions (spikes) for other methods. Required spiking concentrations were given and, for laboratory control standards, required control limits were provided. The use of laboratory control charts was required. It was also required that recoveries be compared to control limits, and that failure to meet control limits would trigger an investigation to determine the cause of the deviation and a correction of the problem. The purpose of the internal quality assurance program was to provide tools for use in the day-to-day quality assurance program, and tools to be used in the retrospective review of the data by EPA for validation and estimation of precision and accuracy. Limited precision and accuracy goals were stated in terms of the control limits that were provided for some of the internal quality control samples.

5. Directives on field replicates (which were to be used to determine interlaboratory precision) and field blanks.

6. All analytical subcontractors who analyzed water samples were required to address points 1 through 5 exactly as described. However, it must be recognized that because of different capabilities of different methods for different analytes, not all types of quality assurance samples were applicable to all methods and analytes.

To reiterate, it was the responsibility of the GCA Corporation to oversee this quality assurance program on a day-to-day basis. It was impossible for EPA to manage this function because more than 6,000 field samples were collected in less than 3 months, and the vast majority of analytical data was not received by EPA until after nearly all the samples had been collected and analyzed.

It was the responsibility of EPA to validate the Love Canal data, and to estimate the precision and accuracy of the validated data. The process of data validation involved the rejection of certain analytical results whenever there was compelling evidence present concerning systematic errors in sampling, preservation, or analysis associated with those results. These functions were accomplished by a retrospective (and intentionally redundant) review of all the quality assurance data collected during the project. The remainder of this Appendix summarizes the water analyses quality assurance program including the specific actions taken as a result of the day-to-day quality assurance program, the data validation process, and the estimation of precision and accuracy.

METHODS SELECTED FOR ANALYSIS OF WATER SAMPLES

Analytical methods for water analyses were selected with the recognition that some trade-offs would be necessary between the desire to acquire the most accurate, precise, and sensitive measurements possible at the current state-of-the-art, and the need to control costs and find a suitable number of subcontractors with the experience and capacity to do the analyses. (See Section 3.3 for details). Therefore, the following methods were selected as the ones that best met the project needs.

For the C_1-C_3 halogenated hydrocarbons and some substituted benzenes, the method selected was EPA's proposed Method 624 as described in the Federal Register, Vol. 44, No. 233, December 3, 1979, p. 69532. Briefly, in this method the analytes are purged from a water sample with a stream of finely divided bubbles of an inert gas, trapped on the sorbent TENAX, thermally desorbed into a packed gas chromatographic column, and detected with a mass spectrometer repetitively scanning from 33 to 260 atomic mass units (amu) at approximately 5-second intervals.

This method was selected because its scope and limitations have been studied, and a number of laboratories had extensive experience with its application to industrial wastewater and drinking water samples. However, the method has not been formally validated in a multilaboratory study, and the same class of compounds may be measured with other methods which would likely give somewhat different results for some analytes. The standard reporting units for Method 624 are micrograms per liter; further information about the method is contained in later parts of this section. Single laboratory precision data for this method was published in the Journal of Chromatographic Science, 1981, 19, 377.

For most of the other organic compounds on the Love Canal water monitoring list, the method selected was EPA proposed Method 625 as described in the Federal Register, Vol. 44, No. 233, December 3, 1979, p. 69540. Briefly, this method partitions analytes in a water sample between the pH adjusted water and an organic solvent, methylene chloride, by mixing the two liquid phases in a separatory funnel or a continuous extractor. After separate partitions were formed at pH 12 and pH 2 (in that order), the individual methylene chloride solutions were either analyzed separately (referred to as Method 625BW) or combined (referred to as Method 625CW) and analyzed. In either case, the organic solvent was dried, concentrated to a low volume, and an aliquot injected into a fused silica capillary gas chromatography column. Mass spectrometric detection used repetitive scanning from 35 to 450 amu at approximately 1- to 2-second intervals. Again, this method was selected because its scope and limitations have been studied, and a number of laboratories had extensive experience with its application to industrial wastewater samples.

The application of the fused silica capillary column was an exercise of an option in a version of Method 625 that was prepared for final rulemaking. Fewer laboratories had experience with these columns, but they were considered essential because of the potentially complex mixtures of organic compounds that could have been present in some Love Canal samples. Method 625 has not been formally validated in a multilaboratory study, and the same class of compounds may be measured with other methods which would likely give somewhat different results for some analytes. The standard reporting units for Method 625 are micrograms per liter; further information about this method is contained in later parts of this section.

The great strength of Methods 624 and 625 is that each method provides the complete 70 electron volt (eV) mass spectrum for each analyte. This, together with the retention index, allows a very high degree of qualitative accuracy, that is, these methods are highly reliable in the identification of the method analytes plus any other analytes that are susceptible to the sample preparation and chromatographic conditions. Another great strength common to these methods is their utility with numerous analytes (1 to 100 or more) simultaneously present in a water sample. Thus, the methods are very cost effective. The weakness of both methods is that they are not the most precise or sensitive mass spectrometric methods that could be chosen. Methods that use selective ion monitoring, like that used for 2,3,7,8-tetrachlorodibenzo-p-dioxin, are both more precise and sensitive, but are also much more costly and time consuming to apply when a large number of analytes are to be measured. The application of fused silica capillary columns with Method 625 may be considered both a strength and a weakness. The strength is the high resolution chromatographic performance of the columns, and the weakness is that the columns are so new that only a small number of laboratories had experience in using them. Also, their availability was limited at the time of the study. Additional information on the scope and limitations of Methods 624 and 625 is presented later in the section titled "Qualitative Analyses."

A few of the chlorinated hydrocarbon pesticides were known to be sensitive to the pH 12 extraction conditions of Method 625, and measurements were desired for certain very toxic pesticides at levels below the detection limits for Method 625. (See the general discussion later concerning detection limits). Therefore, the chlorinated hydrocarbon pesticides and a few related compounds (PCBs), were measured using EPA proposed Method 608 as described in the Federal Register, Vol. 44, No. 233, December 3, 1979, p. 69501. Briefly, in this method the liquid-liquid partition with methylene chloride is carried out with the aqueous phase at pH 5-9. After separation, drying, and concentration of the organic solvent to a low volume, an extract aliquot was injected into a packed gas chromatographic column with an electron capture detector (GC/ECD). The scope and limitations of this method are well known, and many laboratories have extensive experience in using it with a wide variety of water sample types. It was also required that any pesticides identified by this method be confirmed by the analysis of the same extract with GC/MS using Method 625 conditions. Method 608 has undergone formal multilaboratory validation, and a report will be issued in the near future by EPA. The standard reporting units are micrograms per liter, and further information about this method is contained in later parts of this section.

Fluoride was analyzed by either Method 340.1, (Colorimetric, SPADNS with Bellock Distillation) or Method 340.2 (Potentiometric, Ion Selective Electrode). These methods appear in Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020 and are approved for National Pollutant Discharge Elimination System (NPDES) and Safe Drinking Water Act (SDWA) monitoring. Data from these methods are judged to be equivalent. Method 340.1 involves distillation to remove interferences, then the sample is treated with the SPADNS reagent. The loss of color resulting from the reaction of fluoride with the zirconyl-SPADNS dye is a function of the fluoride concentration. In Method 340.2, the fluoride is determined potentiometrically using a fluoride electrode in conjunction with a standard single junction sleeve-type reference electrode and a pH meter having an expanded millivolt scale or a selective ion meter having a direct concentration scale for fluoride.

Nitrate was analyzed by either Method 353.2 (Colorimetric, Automated, Cadmium Reduction) or Method 353.3 (Spectrophotometric, Cadmium Reduction). These methods appear in Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, and are approved for NPDES and SDWA monitoring. The methods are chemically identical, the difference being that Method 353.2 is performed using automated instrumentation. In these methods, a filtered sample is passed through a column containing granulated copper-cadmium (Cu-Cd) to reduce nitrate to nitrite. The nitrite (that which was originally present plus reduced nitrate) is determined by diazotizing with sulfanilamide, and coupling with N-(1-naphthyl)ethylenediamine dihydrochloride, to form a highly colored azo dye that is measured colorimetrically. Separate, rather than combined, nitrate-nitrite values are readily obtained by carrying out the procedure first with, and then without, the Cu-Cd reduction.

Mercury was analyzed by either Method 245.1 (Manual Cold Vapor Technique) or Method 245.2 (Automated Cold Vapor Technique). These methods appear in Methods for Chemical Analyses of Water and Wastes, EPA-600/4-79-020, and are approved for NPDES and SDWA monitoring. These methods are chemically identical, the difference being that Method 245.2 is performed using automated instrumentation. In these methods, mercury is measured by a flameless atomic absorption procedure based on the absorption of radiation at 253.7 nanometers (nm) by mercury vapor. The mercury is reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passes through a cell positioned in the light path of an atomic absorption spectrophotometer. Absorbance (peak height) is measured as a function of mercury concentration and recorded.

Selenium was analyzed by Method 270.2 (Atomic Absorption, furnace technique). This method appears in Methods for Chemical Analysis for Water and Wastes, EPA-600/4-79-020 and is approved for NPDES and SDWA monitoring. The furnace technique was used in conjunction with an atomic absorption spectrophotometer. In this technique, a representative aliquot of sample is placed in the graphite tube in the furnace, evaporated to dryness, charred, and atomized. A light beam from a hollow cathode furnace lamp whose cathode is made of the element to be determined is directed through the furnace into a monochromator, and onto a detector that measures the amount of light absorbed. Absorption depends upon the presence of free unexcited ground state atoms in the furnace. Because the wavelength of the light beam is characteristic of only the metal being determined, the light energy absorbed is a measure of the concentration of that metal in the sample.

All other metallic elements were analyzed by Method 200.7 (Inductively Coupled Plasma-Atomic Emission Spectrometric Method for Trace Element Analysis of Water and Wastes). This method was proposed for NPDES monitoring in the Federal Register, Vol. 44, No. 233, December 3, 1979. For the Love Canal study, the digestion procedure outlined in paragraph 8.4 of the Federal Register was used and the sample was concentrated to one-fifth of the original volume. The basis of the method is the measurement of atomic emission by an optical spectroscopic technique. Samples are nebulized and the aerosol that is produced is transported to the plasma torch where excitation occurs. Characteristic atomic-line emission spectra are produced by a radio frequency inductively coupled plasma (ICP). The spectra are dispersed by a grating spectrometer and the intensities of the lines are monitored by photomultiplier tubes. The photocurrents from the photomultiplier tubes are processed and controlled by a computer system.

A background correction technique was required to compensate for variable background contribution to the determination of trace elements. Background was to be measured adjacent to analyte lines on samples during analysis. The position selected for the background intensity measurement, on either or both sides of the analytical line, was to be determined by the complexity of the spectrum adjacent to the analyte line. The position used must be free of spectral interference and reflect the same change in background intensity as occurs at the analyte wavelength measured. Background correction was not required in cases of line broadening where a background correction measurement would actually degrade the analytical result.

Qualitative Analyses

For those materials named in this report as Method 608 analytes, Method 624 analytes, Method 625 analytes, metals analytes, and anions, the analytical laboratories had available known concentration calibration standards, and the results were reported in micrograms per liter. However, with mass spectrometric methods, compounds not on the analyte list are often detected, and may be identified by their mass spectra. These compounds are designated as qualitative identifications, but concentrations were not measured because appropriate calibration standards were not available. In general, Methods 624 and 625 will observe any compound structurally similar to any Method analyte and with a molecular weight less than 260 and 450, respectively.

SELECTION OF ANALYTICAL SUBCONTRACTORS

Details of the selection process are given in the GCA Corporation document Love Canal Monitoring Program, GCA QA/QC Summary Report. Briefly, EPA provided to the prime contractor the names of a number of laboratories that were known, from past or ongoing environmental monitoring programs, to have the generally required capabilities. Technical evaluation criteria were prepared, proposals were solicited, and a prospective bidders conference was held. The proposals received were reviewed in terms of the evaluation criteria, which included immediate availiability to initiate analyses, quality assurance plan, experience with analyses, and availability of appropriate equipment, personnel, and management. Experience with specific analyses and methods was examined in detail, and capacities for handling samples in a timely manner and preferences for executing certain methods were considered. Finally cost proposals were considered, but this was not the compelling factor. One bidder was not selected because the bid was considered too low to permit the subcontractor to carry out the analyses with the required minimum quality assurance program. Because of the urgency of the program and the deadlines imposed on EPA, no time was available to conduct a preaward interlaboratory study, with actual samples, to refine the selection process.

LIMITS OF DETECTION/QUANTITATION

The American Chemical Society's (ACS) Subcommittee on Environmental Analytical Chemistry published guidelines (*Analytical Chemistry*, 1980, 52, 2242) for data acquisition and data quality evaluation in environmental chemistry. Included in these guidelines are recommendations on limits of detection and quantitation. A procedure was developed by EMSL-Cincinnati to determine a method detection limit that is consistent with the ACS guidelines (*Environmental Science and Technology*, 1981, 1426). As part of the Love Canal quality assurance plan for water analyses, sufficient data were collected to apply this procedure to a limited number of analytes.

Analytical laboratories were required to analyze one laboratory control standard (LCS) for each set of samples processed in a group at the same time on the same day. An LCS was defined as a solution of analytes of known concentration in reagent water. Not all method analytes were included in the LCS's in order to contain costs, and only some were at an appropriate concentration for the procedure. Where data were available and appropriate, the method detection limits were calculated from subcontractor-supplied analytical results; these limits are presented in Table C-1 (laboratory abbreviations are explained in Table 4 of the text). It must be recognized that the results in Table C-1 were computed from measurements made over a period of weeks, rather than the recommended procedure of making all measurements in a single day. Therefore, these values include week to week variability in the method detection limits.

The data in Table C-1, which are specific to Method 624 or Method 625 and the reagent water matrix, cover the range of 0.5 to 79 micrograms per liter with a mean of approximately 14 micrograms per liter. There was considerable variance among the analytical laboratories in method detection limits for a given analyte, and the data suggest that some laboratories were not operating consistently at the state-of-the-art possible with the methods. This is neither unusual nor unexpected.

The data in Table C-1, which were determined in reagent water, may be applied reasonably to the sample matrices of the Love Canal samples. It has been shown that Methods 624 and 625 are not sensitive to the different matrices of the ground, drinking, surface, sump, or storm sewer waters of the Love Canal area. (See the later section on data validation). Similarly, it is reasonable to assume that the method detection limits of most of the organic analytes not shown in Table C-1 fall into the same range of 0.5 to 79 micrograms per liter. Again, considerable variance in detection limits probably existed among the analytical laboratories.

TABLE C-1. MEASURED METHOD DETECTION LIMITS IN MICROGRAMS PER LITER FROM ANALYSES OF LABORATORY CONTROL STANDARDS

	Analytical Laboratory Code					
Analyte	ACEE	PJBL	GSNO	CMTL	TRW	EMSL-Cin
Method 624						
Benzene	26	16	16	11	2.4	4.4
Chlorobenzene	16	17	12	8.3	2.0	6.0
Chloroform	29	17	8.6	--	5.5	1.6
Bromoform	42	40	14	--	1.8	4.7
sym-Tetrachloroethane	23	31	8.1	--	1.7	6.9
Carbon tetrachloride	37	30	13	--	2.7	2.8
Trichloroethylene	26	23	9.4	--	1.6	1.9
Tetrachloroethylene	21	28	13	--	2.4	4.1
Toluene	--	--	--	9.5	--	6.0
Method 625						
1,4-Dichlorobenzene	--	23	20	34	--	5.0
1,2,4-Trichlorobenzene	3.5	9.6	17	32	--	1.9
1,2,3,4-Tetrachlorobenzene	--	17	--	--	--	0.5
2,4,6-Trichlorophenol	--	17	24	--	--	2.7
Pentachlorophenol	--	19	21	30	--	3.6
2,6-Dinitrotoluene	--	16	25	--	--	1.9
4-Nitrophenol	--	6.4	14	21	--	2.4
2-Chloronaphthalene	1.8	15	17	--	--	1.9
β-BHC	--	9.5	--	--	--	4.2
Fluoranthene	2.4	--	20	--	--	2.2
Di-n-butylphthalate	--	27	14	79	--	2.5

Table C-2 gives estimated method detection limits generated from statements in the methods, instrumental detection limits, precision data, and experience using them. They were not rigorously determined but are levels expected to be reported by an analyst using the specified methods. Table C-3 gives measured method detection limits for Method 608 in reagent water. These were measured by one of the subcontractor analytical laboratories, and may be considered typical of the other laboratories' probable performance.

TABLE C-2. ESTIMATED METHOD DETECTION LIMITS FOR ALL LABORATORIES

Analyte	Estimated Detection Limit (µg/liter)
Arsenic	53
Antimony	32
Barium	2
Beryllium	0.3
Cadmium	4
Chromium	7
Copper	6
Lead	42
Mercury	2
Nickel	15
Selenium	10
Silver	7
Thallium	40
Zinc	2
Fluoride	200
Nitrate	100

TABLE C-3. MEASURED METHOD DETECTION LIMITS IN MICROGRAMS PER LITER FOR METHOD 608 IN REAGENT WATER[†]

Analyte	Limit
α-BHC	.003
β-BHC	.006
δ-BHC	.009
γ-BHC	.004
DDD	.011
DDE	.004
DDT	.012
Endosulfan I	.014
Endosulfan II	.004
Endosulfan Sulfate	.066
Heptachlor	.003
Heptachlor Epoxide	.083
Aldrin	.004
Dieldrin	.002
Endrin	.006
Chlordane	.014
Toxaphene	.235
PCB 1242	.065

[†] Measured by SWRI under contract to EMSL-Cincinnati

Data from the Love Canal samples include few reports of concentrations below the method detection limits in Tables C-1, C-2, and C-3, but the range of values reported in Table C-1 is a function of the analytical laboratory. Reports of "trace" for analytes in field samples are the result of subjective judgments by individual laboratories, and represent detections that were of sufficient magnitude to identify the substance, that is, above the limit of detection, but not of sufficient magnitude to measure the amount present, that is, below the method quantitation limit. The meaning of "trace" is further obscured by the variance in method detection limits among laboratories.

Method detection limits were not used to validate data in the Love Canal data base. Variability in quantitation and detection limits among laboratories is a well-known phenomenon and is unavoidable. Some laboratories may have quantified substances that others called "trace," or did not report the substances. These occurrences do not invalidate the results. At the worst, the method detection limits are at the low micrograms per liter level (none exceed 200). Because the conclusions of the study were based on samples contaminated at several orders of magnitude or higher concentrations, that is, parts per million to parts per thousands, the observed variability and magnitudes of the method detection limits had no affect on the overall conclusions of the study. The method detection limits given in Table C-1 that are below approximately 10 micrograms per liter, and given in Tables C-2 and C-3, are believed to represent the state-of-the-art with the methods.

ANALYTICAL LABORATORY PERFORMANCE EVALUATIONS

The Quality Assurance Branch (QAB) of EMSL-Cincinnati conducted extensive performance evaluations (PE) of the analytical laboratories before and during the course of the analytical work. The purpose of this effort was to support the day-to-day quality assurance program of the prime contractor, GCA Corporation. Specially prepared samples of method analytes and detailed instructions were sent overnight to the prime contractor's sample bank at Love Canal, using chain-of-custody procedures. The prime contractor sent these unknown PE samples to the analytical laboratories at approximately 1-month intervals, along with shipments of Love Canal samples. Results from the PE samples were sent directly to QAB, which judged them as acceptable or nonacceptable, and reported each evaluation series immediately to the prime contractor's quality assurance officer.

The prime contractor contacted each subcontractor analytical laboratory by telephone on receipt of the PE sample results, and informed the laboratory of the nature of the results. Discussions centered on the unacceptable values and corrective actions that were required. These results and the required corrective actions were also discussed during laboratory site visits. Table C-4 is a summary of the percentages of acceptable PE results by analytical method analyte group and analytical laboratory. In order to have an acceptable result, the analytical laboratory must have correctly identified the analyte and measured its concentration to within the acceptance limits established by QAB. The general performance of the laboratories in identification was

TABLE C-4. PERCENTAGES OF ACCEPTABLE PERFORMANCE EVALUATION RESULTS

Analytical Method	Number of Analytes	Analytical Laboratory Code								
		PJBL	GSNO	SWRI	CMTL	ACEE	TRW	ERCO	AES	EMSL-Cin
Group One										
Method 624	12	92	77	58	54	33	--	--	--	--
Method 625	12	100[†]	54	58	46	69	--	--	--	58
Method 608	7	88	71	50	88	86	--	--	--	71
Metals Methods	14[‡]	93	--	--	--	--	--	93	--	--
Anions Methods	2	100	--	--	--	--	--	100	--	--
Group Two										
Method 624	12	100	92	--	58	100	--	--	--	92
Method 625	12	58	--	--	50	55	--	--	--	64
Method 608	7	100	--	--	100	63	--	--	--	100
Metals Methods	14	93	--	--	--	--	--	100	--	80
Anions Methods	2[‡]	100	--	--	--	--	--	75	--	75
Total Organic Carbon	1	--	--	--	--	--	--	--	0	--
Group Three										
Method 624	12	100	92	100	--	75	92	--	--	92
Method 625	12	100	47	77	--	67	100	--	--	92
Method 608	7	25	71	86	--	100	78	--	--	100
Metals Methods	14	93	--	--	--	--	--	86	--	100
Anions Methods	2[‡]	50	--	--	--	--	--	100	100[•]	--

[†] Data obtained with conventional packed column

[‡] Two concentrations of each analyte were included in the PE sample.

[•] Only one of four results reported

excellent, with very few analytes missed. The unacceptable results in Table C-4 were due largely to concentrations measurements that were outside the acceptable range. As previously noted, Method 625 employed the relatively new fused silica capillary columns, and there was some initial difficulty in adjusting to this in some laboratories. The PE samples served to assist in this adjustment and to provide data on the applicability of the columns.

One hundred and fifty sets of quality control (QC) samples for Methods 624, 625, 608, trace metals, and nitrate/fluoride were provided to the analytical laboratories to assist their within-laboratory quality control programs. These samples were provided with true values which were retained by the prime contractor, and used in a manner similar to the PE samples.

Information from PE and QC samples was not used to estimate precision and accuracy of the analytical measurements or to validate data for the Love Canal monitoring program, because the PE and QC samples were concentrates in an organic solvent that were added to reagent water at the analytical laboratory before the application of the method. Therefore, although the analytical laboratories were unaware of the true concentrations, they were aware that the samples were PE and QC samples and may have taken unusual care in their analyses. The purpose of the PE and QC samples was to discover problems with the execution of the methods and enable corrective action by the prime contractor on a timely basis.

SAMPLE PRESERVATION

Directions for sample preservation were included in the analytical methods referenced previously. For the organic compound methods (624, 625, and 608), preservation requirements included shipment and storage of samples in iced or refrigerated containers. There was a very high degree of compliance with these preservation requirements.

Maximum holding times for samples before analyses were also specified in the methods. There was a high percentage of samples that were not analyzed within the specified holding times because the magnitude of the analytical requirements of the Love Canal study, plus numerous other on-going environmental studies, literally overwhelmed the national capacity for low-level chemical analyses. The situation was especially severe with regard to the organics analyses using Methods 624 and 625, which employ state-of-the-art gas chromatography/mass spectrometry technology, and Method 608. An analysis of the sample holding times revealed that most Method 608 and Method 625 samples were extracted within the 7-day holding time, and analyzed within the 30-day extract holding time. However, most Method 624 samples were held longer than the 14-day holding time.

A study was undertaken by EMSL-Cincinnati to determine the effects of prolonged sample holding times on the stability of Method 624 analytes. Representative compounds that were known to be susceptible to biological degradation in nonchlorinated water at submicrogram per liter concentrations were added to a nonchlorinated well water sample and a nonchlorinated surface (lake) water sample at concentrations of 100 micrograms per liter. The samples were stored at 6° C in standard sample containers for up to 50 days, the longest period that any Love Canal Method 624 sample was held. Multiple analyses according to Method 624 showed that at this concentration, which was representative of the concentrations found in many Love Canal samples, there were no detectable losses of any of the study compounds over the 50-day period.

An extensive analysis was made of the holding times on all Method 624 samples to seek a correlation between actual holding time and the presence or absence of compounds known to be susceptible to losses at the submicrogram per liter level. The concentration range of concern was generally from 5 to 3,300 micrograms per liter. No correlation was found and it was concluded that the extended holding times for Method 624 samples did not impact the reliability of the data for the compounds susceptible to losses at submicrogram per liter levels. No samples were invalidated because holding times were exceeded.

DATA VALIDATION PROCEDURE

Validation of data is the systematic process of rejecting analytical results whenever compelling evidence exists of systematic errors in sampling, preservation, or analysis associated with those results. Data validation for all methods was based on the retrospective statistical analysis of results from a series of quality assurance samples that were analyzed by all laboratories. The form of the quality assurance was slightly different depending on the method, but a common feature was the analysis by EMSL-Cincinnati of approximately 5 percent of the water samples. Each of the samples analyzed by EMSL-Cincinnati was a member of a group of three that were collected at Love Canal at the same time and place by the sampling team. Two of these samples were delivered to the same subcontractor laboratory with different sample numbers and, therefore, were blind duplicates. The third, with a different sample number, was delivered to EMSL-Cincinnati. The details of the validation process are given in this section. The section entitled "Estimates of Data Precision" contains additional information obtained from the field triplicate samples.

Methods 624 and 625

For Methods 624 and 625, the principal validation tool was a series of quality control compounds, often called surrogate analytes, that were added to each water sample. The compounds selected as surrogates were valid method analytes that were neither commercially produced nor naturally occurring. Therefore, it was highly unlikely that any of them would be found in any environmental sample. The compounds fluorobenzene and 4-bromofluorobenzene were added by the analytical laboratories to each water sample intended for Method 624 at a concentration in the range of 5 to 25 micrograms per liter. The compounds 2-fluorophenol, 1-fluoronaphthalene, and 4,4'-dibromooctafluorobiphenyl were added by the analytical laboratories to each water sample intended for Method 625 at a concentration in the range of 5 to 25 micrograms per liter. Analytical laboratories reported the quantities added (true values) and the amounts measured. Statistics were computed by EMSL-Cincinnati in terms of the percentage recoveries of the amounts added to allow comparisons among laboratories that added different amounts within the specified range.

The recoveries (percentages of the true values) for the five surrogates in both methods by all analytical laboratories were analyzed statistically to determine if there were any significant differences related to the types of samples, that is, ground water, drinking water, surface water, sump water, or storm sewer water. No statistically significant differences were found, that is, there were no unusual matrix effects in any of these sample source types, and all subsequent data analyses were conducted by combining results from different sample types. The recoveries for each surrogate were tested for normality using several standard statistical tests. The conclusion was that the data were approximately normally distributed, and that use of standard deviations and statistical tests based on normal theory were justified.

The standard for performance with the surrogate analytes was established with the 5 percent of the water samples analyzed by EMSL-Cincinnati, which developed Methods 624 and 625 and operated in control based on extensive experience. Table C-5 contains a summary of the statistics and the lower control limits that were expressed as 99 percent confidence limits. No upper control limits were used because there were very few reports of excessively high recoveries. High measurements are indicative of positive interferences that were precluded by the nature of the surrogates and the high selectivity of the mass spectrometric detector. Low percentages of true values are indicative of losses due to careless handling, reduced equipment efficiency, or inadequate sensitivity. Lower control limits were set at the 99 percent confidence level to ensure the high probability that any recoveries below them were due to nonrandom systematic method errors.

It should be pointed out that the lower acceptance limits (Table C-5) for the three Method 625 surrogates 2-fluorophenol, 1-fluoronaphthalene, and 4,4'-dibromooctafluorobiphenyl were not the same as the lower control limits provided initially to the analytical subcontractors for use in their internal quality control programs. The lower internal quality control limits that were provided to the analytical subcontractors (Quality Assurance Plan, Love Canal Study, LC-1-619-206) were based on data obtained from Method 625 using a packed gas chromatography column. As noted previously in the section entitled "Methods Selected for the Analysis of Water Samples," fused silica capillary column technology was selected for use with Method 625. It was recognized that while significant advantages were to be gained through the selection of this relatively new column technology, no data on precision would be available prior to the study. Therefore, packed column control limits were provided as guidelines for use by the analytical subcontractor laboratories.

As part of the retrospective data validation process, acceptance limits were developed based on the actual experience derived from the fused silica capillary columns. These limits, which are reported in Table C-5, are somewhat lower than the packed column control limits and reflect relatively greater variability in measurements obtained from the capillary columns. The relatively greater variability in capillary column measurements was judged acceptable in light of the considerable advantages derived from the new technology. In addition, it should be pointed out that even though somewhat greater variability was obtained from the fused silica capillary column technology, the data validation confidence limits were not altered. That is, the original packed column control limits and the derived capillary column acceptance limits were both set at the 99 percent confidence level.

In order to invalidate the data from a sample, it was required that at least two surrogate compounds in the sample have their recoveries out of control. Out of control low recoveries of two surrogate compounds is strongly suggestive of poor method execution, and the high probability that all other method analytes would be measured low or completely missed because of poor method execution.

With Method 624, data from five Love Canal samples were invalidated. One of these was a field blank, three were sump samples, and one was a ground-water sample. Three subcontractor laboratories were represented, and no analytes were reported in any of these samples except the laboratory contaminant methylene chloride and some trace levels of other analytes. (See the next section). With Method 625, data from 12 samples were invalidated because at least 2 of the 3 surrogate recoveries were below the lower control limits shown in Table C-5. The invalidated data did not include any significant analyte measurements, but included several traces and large quantities of the phthalate ester laboratory contaminants. The invalidated Method 625 data were mainly from sump, ground water, or field blank samples and included measurements from four laboratories.

TABLE C-5. SUMMARY STATISTICS AND LOWER CONTROL LIMITS FOR METHODS 624 AND 625 SURROGATES FROM EMSL-CINCINNATI MEASUREMENTS

Surrogate Analyte	Number of Samples	Mean Recovery (Percent)	S.D.	Relative Standard Deviation (Percent)	Lower Control Limit (Percent)
Fluorobenzene	22	99	10	10	68
4-Bromofluorobenzene	22	99	13	13	60
2-Fluorophenol	26	57	20	36	1
1-Fluoronaphthalene	26	73	23	32	2.8
4,4'-Dibromooctafluorobiphenyl	26	79	24	30	8.3

S.D.: Standard deviation

Invalid Ground-Water Samples

There were 28 ground-water Method 624 samples from bedrock B Wells that were contaminated only by chloroform. It is well established that this compound is formed during the disinfection of water with chlorine to prepare water suitable for human consumption. It was determined by the EPA Environmental Research Laboratory in Ada, Oklahoma, which was responsible for the ground-water monitoring program, that the wells from which these samples were taken were not purged adequately prior to sampling. Ordinary hydrant water (drinking water) was used as a drilling fluid during the bedrock well drilling process, and type B Wells were supposed to have been purged of these fluids before sampling. Consequently, all samples from these wells were invalidated, not because the analyses were at fault, but because the samples may not have been representative of the ground water. While a few other ground-water samples also contained chloroform, other contaminants were present; therefore, samples from these wells were not invalidated.

Laboratory Contamination

Methylene chloride was the solvent used in Method 625, and it was an analyte in Method 624. There were 84 water samples analyzed by Method 624 in which methylene chloride was the only reported analyte, and 94 percent of these reports came from 2 laboratories, CMTL and GSNO. This evidence strongly suggested the presence of laboratory contamination that was not unexpected with such highly sensitive analytical methodology. Therefore, although a few reports of methylene chloride may have been valid, the overwhelming number were very likely laboratory contaminants, and it was impossible to distinguish the former from the latter. Consequently, all reports of methylene chloride in water samples were deleted from the validated data.

Late in the data reporting period, after the methylene chloride problem was discovered, one of the laboratories was inspected by EPA personnel. A large opening was found in the laboratory between the area where the methylene chloride extractions were conducted and the room where the analytical instrumentation was located. This finding supported the strong probability that methylene chloride was a laboratory contaminant in at least one of the laboratories.

There were a very large number of reports for two compounds, bis(2-ethylhexyl)phthalate and dibutyl phthalate, in both real and quality control samples. There also were significant differences in the amounts of these compounds reported in several laboratory duplicates. Finally, it is well-known that these compounds are widely used plasticizers and are frequently used in bottle cap liners. Many of the early samples that arrived at EMSL-Cincinnati for analysis had poorly fitted and leaking Teflon cap liners. This was corrected later in the study and fewer of these phthalates were observed. On this basis, all reports of these two compounds in samples were judged highly unreliable and all reports were removed from the validated data.

Method 608

Validation of data from samples analyzed by Method 608 was based on the quality control requirement that an LCS was to be analyzed with each batch of samples processed in a group at the same time. Recoveries of LCS analytes were evaluated, and if unacceptable recoveries were reported, all of the data obtained with Method 608 on that day by that laboratory were invalidated. Using this approach, all the data obtained by one laboratory on one day were invalidated because the laboratory reported zero LCS recoveries, suggesting major method execution errors or instrument failures.

Method 608 employs an electron capture gas chromatographic detector, and is subject to false positive identifications. In order to minimize these errors, two column confirmation and gas chromatography/mass spectrometry (GC/MS) confirmations were required for all Method 608 results. However, GC/MS confirmation was limited by the difference in detection limits between the methods. Users of the Love Canal data should be aware of the probability that low level, less than 0.5 micrograms per liter, measurements by Method 608 were not confirmed by GC/MS.

Metals and Anions

Validation of data from samples analyzed for metals and the anions fluoride and nitrate was based on the quality control requirement that a certain percentage of samples were spiked with the analytes at a specified concentration. Specifically, the first 10 samples from each type of water sample (ground, sump. drinking, storm sewer, and surface), and 5 percent of the remaining samples, were spiked with these analytes at concentrations in the range of 10 to 10,000 micrograms per liter. The concentrations were selected as appropriate for the analyte, and the laboratories were required to measure the background levels first and subtract these from the spike concentrations before the percentage recoveries were computed.

The standard of performance with these methods was established by the results obtained from EMSL-Cincinnati measurements of 5 percent of the samples. The EMSL-Cincinnati recoveries for the 14 metal and 2 anion parameters were tabulated by parameter and sample source type. The mean recovery and standard deviation were calculated for the total population and for each sample type. A mean recovery of ±11 percent of the actual spike value (based on the total population) was used as the criterion for valid data.

The spike recovery data from the other analytical laboratories were compared with the criterion, and data meeting it were accepted as valid. For some data, poor spike recoveries could be traced to improper spiking technique, and the data were ruled valid. In other cases, no explanation could be found for the poor recoveries and all data analyzed on that day, in that sample source type, by that laboratory, were ruled invalid. Overall, some data from two laboratories were invalidated, and in every case these were all measurements of one metal in a particular source type on a particular day.

ESTIMATES OF DATA PRECISION

The purpose of the field triplicate samples described at the beginning of the data validation section was to establish interlaboratory and intralaboratory precision. In addition, some methods required taking two aliquots of 10 percent of the samples to obtain further information about intralaboratory precision. However, a high percentage of the total samples gave all analytes below detection limits, and insufficient information was available to estimate the precision of the measurements from these samples.

With Method 625, close to 75 percent of all water samples contained no analytes above the method quantitation limit. An additional 10 percent of the water samples contained only trace quantities. These findings were reflected in the results obtained with the field triplicate samples and laboratory duplicates, and insufficient results were available from these samples to estimate precision. Similar observations were made with all other methods.

Data precision may be estimated using the results of the measurements of the laboratory control standards that were described earlier under Limits of Detection/Quantitation. This is a less desirable approach because the LCS measurements do not include the variability associated with sampling, transportation, storage, and preservation of samples. Also, these data may have been obtained over a period of weeks by some laboratories, and the values may include week-to-week variations that may significantly exceed variations within a given analysis day. Nevertheless, lacking the information from the replicate field samples, the LCS measurements may be used to provide rough estimates of data precision.

Table C-6 shows the relative standard deviations for replicate measurements of Method 624 and Method 625 analytes in LCS samples. No statistics were computed unless at least five replicate measurements were available. Some laboratories did not analyze a sufficient number of some types of samples to accumulate five LCS measurements. All the LCS concentrations were in the range of 10 to 50 micrograms per liter. The precision of any single measurement of a Method 624 or Method 625 analyte in any Love Canal water sample, at the 95 percent confidence level, may be estimated using the formula:

$$\text{Analytical Result} \pm 2 \times (\text{RSD from Table C-6}).$$

The RSD should be selected from Table C-6 according to the analyte measured and the laboratory analyzing the sample. If the exact analyte is not in Table C-6, a structurally similar analyte may be used; for example, if the analyte of interest is 2-nitrophenol, the RSD for 4-nitrophenol may be used. If RSD data for the reporting laboratory is not in Table C-6, use the mean RSD of all laboratories reporting that analyte. Additional single laboratory precision data for Method 624 was published in J. Chromatographic Science, 1981, 377. For metals and anions, a similar estimate may be made using the relative standard deviations presented in Table C-7.

Precision estimates were not used to validate the Love Canal data. Data validation procedures are explained in detail in the previous section entitled, "Data Validation Procedures."

ESTIMATES OF DATA ACCURACY

Method 624 is well established as a method without bias when it is used to analyze samples that have a matrix similar to the

TABLE C-6. RELATIVE STANDARD DEVIATIONS (RSD) FOR ORGANIC ANALYTES IN LABORATORY CONTROL STANDARDS

	Analytical Laboratory Code					
Analyte	ACEE	PJBL	GSNO	CMTL	TRW	EMSL-Cin†
Method 624						
Benzene	42	11	27	12	4.3	7.4
Chlorobenzene	28	12	25	9.4	3.9	10
Chloroform	55	12	16	--	5.3	3
Bromoform	77	39	42	--	2.6	7.6
sym-Tetrachloroethane	38	31	29	--	2.7	12
Carbon tetrachloride	53	17	33	--	14	4.5
Trichloroethylene	44	18	19	--	5.6	2.9
Tetrachloroethylene	36	23	30	--	7.6	6.7
Toluene	--	--	--	11	--	9.3
Method 625						
1,4-Dichlorobenzene	--	37	79	32	--	17
1,2,4-Trichlorobenzene	--	30	62	32	--	15
1,2,3,4-Tetrachlorobenzene	--	32	--	--	--	--
2,4,6-Trichlorophenol	--	47	68	--	--	20
Pentachlorophenol	--	52	59	87	--	25
2,6-Dinitrotoluene	--	45	70	--	--	16
4-Nitrophenol	--	40	--	109	--	42
2-Chloronaphthalene	--	32	56	--	--	12
β-BHC	--	30	--	--	--	7.7
Fluoranthene	--	--	55	--	--	21
Di-n-butylphthalate	--	38	73	77	--	17

†As reported in J. Chromatographic Science, 1981, 377; all data obtained during a single work shift

TABLE C-7. RELATIVE STANDARD DEVIATIONS (RSD) FOR INORGANIC ANALYTES IN WATER SAMPLES

	Analytical Laboratory Code			
Analyte	ERCO	PJBL	SWRI	EMSL-Cin
Arsenic	8.1	33	11	11
Antimony	12	38	36	43
Barium	5.9	46	21	4.3
Beryllium	5.7	12	29	7.3
Cadmium	13	14	25	5.6
Chromium	11	14	38	8.1
Copper	17	12	32	5.3
Lead	13	11	31	16
Mercury	19	25	25	10
Nickel	12	10	30	30
Selenium	13	23	47	8.7
Silver	12	39	46	3
Thallium	16	38	15	15
Zinc	20	11	22	19
Fluoride	10	10	6	13
Nitrate	82	15	11	2.6

reagent water matrix used to calibrate the procedure. The sample types analyzed in this study had no unusual matrix effects, and the Method 624 results are without bias. (See the discussion of surrogate recoveries as a function of water sample type in the Data Validation Procedures section).

Data from Methods 625 and 608 have a significant bias because the liquid-liquid partition is not 100 percent efficient, and these methods do not provide a procedure to correct for these losses. Recoveries of Method 625 and 608 analytes generally fall in the 50 to 90 percent range (Table C-5), and this was confirmed in this study by measurements of a number of analytes in laboratory control standards.

Measurements of metals and the two anions were without significant bias in the Love Canal samples. This was discussed previously in the section on data validation.

Estimates of data accuracy were used to validate the Love Canal data. These procedures for surrogate analytes and other analytes were described in detail in the "Data Validation Procedures" section.

SUMMARY OF MAJOR ACTIONS TAKEN AS A RESULT OF THE GCA CORPORATION'S QUALITY ASSURANCE FUNCTION

The activities of the prime contractor in the day-to-day quality assurance program are described in detail in the Love Canal Monitoring Program, GCA QA/QC Summary Report on the Love Canal study. The purpose of this section is to summarize briefly the major QA actions initiated by the GCA Corporation.

The prime contractor routinely discussed, by telephone and during site visits, the results of the external quality assurance samples with the analytical laboratories. Requirements for corrective action were provided during these discussions. The prime contractor also monitored the results from the internal quality assurance program, and discussed these with the analytical laboratories during telephone conversations and site visits. Again, requirements for corrective action were provided.

One significant action that resulted from the day-to-day quality assurance program was the removal of the laboratory PJBL from the analysis of samples by Method 625 in water, soils, and sediment. During a site visit and during discussions of the internal and external quality assurance samples, it was discovered that PJBL was using packed columns with Method 625, and did not have the capability to analyze the samples with the fused silica capillary columns.

All previous results using Method 625 provided by PJBL were therefore invalidated, work on Method 625 was suspended at PJBL, and TRWW replaced PJBL for the analysis of Method 625. Eventually, PJBL developed the capability to use the fused silica capillary columns and all the sample extracts were reanalyzed.

Details of this incident and other activities of the prime contractor are given in the Love Canal Monitoring Program, GCA QA/QC Summary Report referenced earlier.

APPENDIX D
QUALITY ASSURANCE FOR SOIL, SEDIMENT, AND BIOTA SAMPLES

OVERVIEW OF QUALITY ASSURANCE PROGRAM

This Appendix summarizes the quality assurance activities and data validation procedures used in the soil, sediment, and biota analyses. Details of the quality assurance plans are presented in a four-part document entitled Quality Assurance Plan, Love Canal Study, LC-1-619-206, that was issued by the GCA Corporation, the prime contractor for the project, and approved by the EPA quality assurance officers. As was mentioned previously, that document consists of a main volume plus Appendix A on sampling procedures, Appendix B on analytical procedures, and Appendix Q on the subcontractor's QA plans. A more detailed discussion of the results of the prime contractor's and subcontractor's quality assurance efforts is contained in the Love Canal Monitoring Program, GCA QA/QC Summary Report prepared by the GCA Corporation. These documents (available from NTIS) should be consulted for more details on the project.

The design of the soil, sediment, and biota monitoring program at Love Canal and the related quality assurance plans were developed by EPA and described in detail to the prime contractor. This guidance was intended to establish minimum standards for quality assurance, and it was expected that the GCA Corporation and subcontractors would amplify the requirements in their plans. During the design, study, and data evaluation phases of the Love Canal project, the plans and results were reviewed by an independent group, the sampling protocols study group of the EPA's Science Advisory Board.

It was the responsibility of the prime contractor to oversee the day-to-day quality assurance programs of the subcontractors using the guidance provided by EPA and the approved plans. This guidance formed the basis for the GCA Corporation quality assurance plan document that was mentioned earlier. Briefly, the soil, sediment, and biota quality assurance guidance provided by EPA included the following items.

1. Directives on sample collection

2. Directives on analytical methods

3. Directives on the external quality assurance program, including the use of performance evaluation samples and quality control samples provided by EMSL-Cincinnati. The purpose of the external quality assurance program was to give the prime contractor some of the tools necessary to oversee the day-to-day quality assurance program.

4. Directives on the internal quality assurance program including required measurements of gas chromatography/mass spectrometry (GC/MS) reference compounds, method blanks, laboratory control standards, laboratory duplicates, surrogate analytes for modified Methods 624 and 625, and known additions (spikes) for other methods. Required spiking concentrations were given. The purpose of the internal quality assurance program was to provide tools for use in the day-to-day quality assurance program, and tools to be used in the retrospective review of the data by EPA for validation and estimation of precision and accuracy.

5. Directives on field replicates, which were to be used to determine interlaboratory precision, and field blanks

6. All analytical subcontractors who analyzed soil, sediment, and biota samples were required to address points 1 through 5 exactly as described. However, it must be recognized that because of different capabilities of different methods for different analytes, not all types of quality assurance samples were applicable to all methods and analytes.

To reiterate, it was the responsibility of the GCA Corporation to oversee this quality assurance program on a day-to-day basis. It was impossible for EPA to manage this function because over 6,000 field samples were collected in less than 3 months, and the vast majority of analytical data was not received by EPA until nearly all the samples were collected and analyzed.

It was the responsibility of EPA to validate data for the Love Canal data base and to estimate the precision and accuracy of the validated data. Validation involved the rejection of certain analytical results whenever there was compelling evidence of systematic errors in sampling, preservation, or analysis associated with those results. These functions were accomplished by a retrospective (and intentionally redundant) review of all the quality assurance data collected during the project. The balance of this Appendix summarizes the quality assurance program including the specific actions taken as a result of the day-to-day quality assurance program, the data validation process, and the estimation of precision and accuracy.

METHODS SELECTED FOR ANALYSIS OF SOIL AND SEDIMENT SAMPLES

Analytical methods for soil and sediment analyses were selected with the recognition that some trade-offs would be necessary between the desire to acquire the most accurate, precise, and sensitive measurements possible at the current state-of-the-art, and the need to control costs and find a suitable number of subcontractors with the experience and capabilities to do the analyses. Some of these trade-offs were discussed in Section 3.3 of the report, with emphasis on the pre-study goals for accuracy, precision, and limits of detection/quantitation. The following methods were selected as the ones that best met the project needs.

For the C_1-C_3 halogenated hydrocarbons and some substituted benzenes, the method selected was a modification of EPA's proposed Method 624 as described in the Federal Register, Vol. 44, No. 233, December 3, 1979, p. 69532, and presented in Appendix C, Quality Assurance for Water Samples. The modifications to Method 624 for soil and sediment analyses consisted of placing a mixture of soil or sediment and reagent water in a modified screw-top vial and purging as in Method 624, except that the sample-water mixture was heated to 55°C during the purge. The rationale for this modification was that the method analytes are not sorbed strongly on the soil/sediment particulate matter, because their structures do not generally contain polar functional groups, and the analytes have typically low solubilities in water and relatively high vapor pressures at ambient temperatures. Therefore, at 55°C and with the agitation of the purge gas, the method analytes would rapidly equilibrate between the sorbed and liquid phases, and be subject to purging from the water as in Method 624.

The modified soil and sediment Method 624, which is designated Method 624PS in the Love Canal data base, has not been formally validated in a multilaboratory study. Only unpublished internal EPA reports describe the method and preliminary results. This same class of compounds may be measured with other methods which would likely give somewhat different results for some analytes. Method 624PS is not limited to the analytes listed in Method 624 (as amended for the Love Canal study), but will observe any compound structurally similar to the method analytes and with similar physical and chemical properties. The method is limited to compounds with a molecular weight from 33 to 260 atomic mass units (amu), because this was the limit of the mass spectrometer scan. The standard reporting units for Method 624PS are micrograms per kilogram, and further information about the method is contained in later parts of this section.

For most of the other organic compounds on the Love Canal monitoring list, the method selected was a modification of EPA's proposed Method 625 as described in the Federal Register, Vol.

44, No. 233, December 3, 1979, p. 69540, and presented in Appendix C, Quality Assurance for Water Samples. The modifications to Method 625 for soil and sediment analyses consisted of extracting the pH adjusted soil or sediment with methylene chloride using a high speed mechanical stirrer. Separate extractions at pH 12 and pH 2 (in that order) were followed by centrifuging to facilitate phase separation. The separated individual methylene chloride solutions were dried, concentrated to a low volume, and either analyzed separately (Method 625BS in the Love Canal data base) or combined and analyzed (Method 625CS in the Love Canal data base). The optional Method 625 fused silica capillary gas chromatography column was used with modified Method 625. In addition, an optional gel permeation chromatographic procedure was included in the method for preprocessing heavily contaminated samples before gas chromatography, but it was determined early in the study that preprocessing was not necessary for all samples. Only two analytical laboratories, GSRI and SWRI, received heavily contaminated soil/sediment samples in the early part of the study and became accustomed to routine application of the gel permeation chromatographic procedure.

The principal modifications to Method 625 for soil and sediment analyses were the use of a high speed mechanical stirrer, centrifuging to separate phases, and the optional gel permeation chromatography. These modifications to Method 625, originally established to allow the application of Method 625 to sludges formed in wastewater treatment plants, were developed previously by the Midwest Research Institute (MWRI) under contract to EPA. A final report on this project has been prepared, peer reviewed, and is scheduled for release during 1982. This report, and other internal EPA studies, indicated that the modifications were successful, and the method was a viable choice. In particular, the MWRI report indicated good recoveries from the gel permeation chromatographic preprocessing, which makes possible valid comparisons of results from samples receiving and not receiving this treatment. Nevertheless, two alternative extraction procedures were considered, and tested briefly with Love Canal soil and sediment samples, before the final choice was made in favor of modified Method 625.

The two alternative extraction procedures considered were as follows. First, an extraction procedure using a 1:1 mixture of acetone and hexane with the high speed mechanical stirrer was tested, but qualitatively had no apparent advantages. And second, an extraction procedure based on steam distillation that had been used by the New York State Department of Health for the analysis of Love Canal samples was also tested briefly. This method was rejected because it may produce chemical artifacts, such as nitroaromatic compounds, that are probably formed at the temperatures required for steam distillation. Other thermally promoted chemical changes were considered likely, which also made the method unattractive.

The modified Method 625 selected for the analysis of Love Canal soils and sediments has not been formally validated in a multilaboratory study. This same class of compounds may be measured with other methods which would likely give somewhat different results for some analytes. Modified Method 625 is not limited to the analytes listed in Method 625 (as amended for the Love Canal study), but will observe any compound structurally similar to any method analyte and with similar physical and chemical properties. The method is limited to compounds with a molecular weight from 35 to 450 amu, because that was the limit of the mass spectrometer scan. The standard reporting units for modified Method 625 are micrograms per kilogram, and further information about the method is contained in later parts of this section.

The great strength of modified Methods 624 and 625 is that each method provides the complete 70 eV mass spectrum for each analyte. This, together with the retention index, allows a very high degree of qualitative accuracy, that is, these methods are highly reliable in the identification of the method analytes plus any other analytes that are susceptible to the sample preparation and chromatographic conditions. Another great strength common to these methods is their utility with numerous analytes (1 to 100 or more) simultaneously in the same sample. Thus, the methods are very cost effective. The weakness of both methods is that they are not the most precise or sensitive mass spectrometric methods that could be chosen. Methods that use selected ion monitoring, like that used for 2,3,7,8-tetrachlorodibenzo-p-dioxin, are both more precise and sensitive, but also more costly to apply when a large number of analytes are to be measured. The application of fused silica capillary columns with modified Method 625 may be considered both a strength and a weakness. The strength is the high resolution chromatographic performance of the columns, and the weakness is that the columns are so new that only a limited number of laboratories had experience in using them. Also, their availability was limited at the time of the study.

A few of the chlorinated hydrocarbon pesticides were known to be sensitive to the pH 12 extraction conditions of modified Method 625, and measurements were desired for certain very toxic pesticides at levels below the detection limits for modified Method 625. (See a later general discussion of detection limits). Therefore, the chlorinated hydrocarbon pesticides and a few related compounds (PCBs) were measured using modifications to methods that are described in Manual of Analytical Methods for the Analysis of Pesticides in Humans and Environmental Samples, EPA-600/8-80-038, June, 1980. Soils were extracted by a procedure entitled "Organochlorine Insecticides in Soils and Housedust" in the aforementioned report, but the extracts were analyzed using the conditions described in EPA proposed Method 608 as described in the Federal Register, Vol. 44, No. 233, December 3, 1979, p. 69501.

Briefly, the air dried and sieved soil was extracted in a Soxhlet apparatus with a 1:1 mixture of acetone and hexane, the extract was concentrated, partitioned on alumina and florisil, and analyzed using a packed gas chromatography column with an electron capture detector (GC/ECD). Sediments were extracted by a procedure entitled "Organochlorine and Organophosphorus Insecticides in Bottom Sediment" in the same report, but were again analyzed with the Method 608 conditions referenced previously. The sediments were air dried, blended in a mixer with sodium sulfate, extracted in a chromatographic column with a 1:1 mixture of acetone and hexane, and the extract was added to water. The water was then extracted in a separatory funnel with 15 percent methylene chloride in hexane, the extract was concentrated, partitioned on florisil, and analyzed with the Method 608 conditions.

It was required that any pesticides identifed by GC/ECD (Method 608) be confirmed by the analysis of the same extract with gas chromatography/mass spectrometry using the Method 625 conditions. The complete soils and sediments methods have not undergone formal multilaboratory validations. The standard reporting units are micrograms per kilogram, and further information about these methods is contained in later parts of this section. The soil and sediment GC/ECD method is referred to as modified Method 608 in the balance of this Appendix.

All elements except mercury were analyzed by either direct flame aspiration or furnace atomic absorption spectrometry. The samples were digested with nitric acid and hydrogen peroxide prior to measurements using the methods described in Methods for Chemical Analysis for Water and Wastes, EPA-600/4-79-020. For furnace atomic absorption methods, background correction and calibration with the method of standard additions was required; for direct flame aspiration, justification was required to omit calibration by standard additions. Mercury was measured by the cold vapor atomic absorption procedure as described in Methods for Determination of Inorganic Substances in Water and Fluvial Sediments, Book 5, Chapter A1, U.S. Geological Survey, 1979. The mercury is reduced to the elemental state, aerated from solution, and passed through a cell positioned in the light path of an atomic absorption spectrometer. Parts of or all of the methods for the elements have been validated in multilaboratory studies. The standard reporting units for elemental measurements are micrograms per kilogram. More detailed information about the atomic absorption methods and background correction is presented in Appendix C, in the section entitled "Methods Selected for Analysis of Water Samples".

Qualitative Analyses

For those materials named in this report as modified Method 608 analytes, modified Method 624 analytes, modified Method 625 analytes, and metals analytes, the analytical laboratories had available known concentration calibration standards, and the results were reported in micrograms per kilogram. However, with mass spectrometric methods, compounds not on a targeted analyte list are often detected, and may be identified by their mass spectra. When observed, these compounds are designated as qualitative identifications, but concentrations were not measured because appropriate calibration standards were not available. In general, modified Methods 624 and 625 will observe any compound structurally similar to any method analyte and with a molecular weight less than 260 and 450 respectively. Qualitative analyses were required of the 20 most abundant total ion current peaks in the chromatogram that were nontarget compounds.

METHODS SELECTED FOR ANALYSIS OF BIOTA SAMPLES

Analytical methods for biota analyses were selected with the overall goal of the biological monitoring program in mind. This goal was to provide limited, suggestive indication of the accumulation of substances monitored in biological systems, thereby potentially increasing the sensitivity of the entire monitoring program. Therefore, not all target analytes discussed under water samples (Appendix C) and soil and sediment samples (previous section of this Appendix), were determined in all biota samples. Because the biological monitoring effort was very limited, analytical methods and quality assurance procedures were selected to minimize costs and to keep the effort in perspective with the overall study.

Because of EPA's very limited experience and capabilities in chemical analyses of biota samples, no pre-study precision, accuracy, or detection limit goals were established. The following methods were selected as the ones that best met the project needs.

Mouse, crayfish, and earthworm tissue were analyzed for the Method 625 analytes (Appendix A) plus the qualitative analytes described under soils and sediments. The procedure used was an adaptation of one published in Analytical Chemistry, 1978, 50, 182 (from the EPA Environmental Research Laboratory, Duluth, Minnesota) that was intended for high fat content fish tissue. The adaptation is described in Organics Analysis Using Gas Chromatography-Mass Spectrometry (W. L. Budde and J. W. Eichelberger, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1979). Briefly, in this method frozen tissue samples were blended with solid carbon dioxide and anhydrous sodium sulfate, and the dried mixture extracted in a Soxhlet apparatus with a 1:1 mixture of acetone and hexane. The extract was concentrated to a low volume and the fatty material was separated from the compounds of interest with gel permeation chromatography. The concentrated eluate was examined by gas chromatography/mass spectrometry using the conditions described for modified Method 625 in the soils and sediments section of this Appendix. This method has not been validated in a multilaboratory study, and this same class of compounds may be measured with other methods which would likely give somewhat different results for some analytes. The standard reporting units are micrograms per kilogram.

Potatoes and oatmeal were analyzed for halogenated Method 624 analytes. The procedure employed a headspace sampling technique after digestion of a small sample with hot sulfuric acid in a sealed container. The headspace gases were analyzed with a packed gas chromatographic column using a halogen specific Hall detector. All results from this method must be considered tentative because they were not confirmed by mass spectrometry or another spectrometric technique. All concentrations were considered crude estimates for exploratory purposes because the method was essentially untested.

Metals were measured in hair from dogs and mice, and in silver maple tree leaves. Hair was cleaned, digested in nitric acid, and analyzed using the atomic absorption methods described in Appendix C. The furnace technique was employed for most metals except cadmium, where direct aspiration in a flame was permitted, and mercury, where the cold vapor technique was used.

Metals in vegetation were measured with atomic absorption or inductively coupled argon plasma (ICAP) emission spectrometry. Vegetation was digested with nitric and perchloric acid and, in some cases, sulfuric acid. The instrumental techniques are described in Appendix C of this Volume.

METHODS SELECTED FOR RADIOACTIVITY

Soil, sediment, and water samples were examined for radioactivity. Because the methods used for water samples were very similar to those used for soil and sediment samples, they were not described previously in Appendix C.

Soil, sediment, and water samples were collected in 300 milliliter Teflon-lined aluminum cans. The analysis for gamma-emitting radionuclides was accomplished with a well shielded computerized gamma ray spectrometer using a solid state high resolution gamma ray detector (lithium drifted germanium or intrinsic germanium). This analysis required no sample preparation, and the samples were not even removed from the sealed aluminum cans. Because samples were not removed from their containers, the possibility of laboratory losses or contamination was essentially eliminated, and the principal quality assurance activity was a daily instrument calibration and frequent measurements of calibration check samples. All radioactivity measurements were performed by EMSL-Las Vegas. This EPA laboratory is also responsible for conducting a nationwide quality assurance program for measurements of radionuclides in environmental samples. All standards used were traceable to the National Bureau of Standards.

The method detection limit for a given radionuclide is dependent on the abundance of the gamma rays emitted and their energy. For cesium-137 the detection limit is approximately 50 picocuries per liter of water and 40 picocuries per kilogram of soil or sediment. After counting the gamma emissions from drinking water samples, the containers were opened, the water was distilled, and an aliquot of the distillate mixed with a liquid scintillating material. The mixture was then analyzed for tritium by scintillation counting. The detection limit for this procedure is approximately 300 to 400 picocuries per liter. (See Table 13 and Section 4.3.3 in the text for additional information).

SELECTION OF ANALYTICAL SUBCONTRACTORS

Details of the analytical subcontractors selection process are given in the QA/QC summary report on the Love Canal project prepared by the GCA Corporation. Briefly, the process included: (1) the provision by EPA to the prime contractor of the names of a number of laboratories that were known from past or ongoing environmental monitoring programs to have the generally required capabilities; (2) technical evaluation criteria were prepared; (3) proposals were solicited; and (4) a prospective bidders conference was held. The proposals received were reviewed in terms of the evaluation criteria, which included immediate availability to initiate analyses, quality assurance plan, experience with analyses, and availability of appropriate equipment, personnel, and management. Experience with specific analyses and methods was examined in detail, and capabilities for handling samples in a timely manner (and preferences for executing certain methods) were considered. Finally, cost proposals were considered, but this was not a compelling factor. One bidder was not selected because the bid was considered too low to permit the subcontractor to carry out the analyses with the minimum required quality assurance program. Because of the urgency of the program and the deadlines imposed on EPA, there was no time to conduct a preaward interlaboratory study with actual samples to refine the selection process.

LIMITS OF DETECTION/QUANTITATION

In Appendix C, it was possible to calculate limits of detection (LOD) for several methods from subcontractor supplied results of the analyses of laboratory control standards. A laboratory control standard was defined as a solution of analytes of known concentration in reagent water. By contrast, in the soil, sediment, and biota media, there are substantial impediments to the measurement of limits of detection. In particular, it is very difficult to add a known amount of an analyte or analytes to a soil, sediment, or biota sample and simulate the natural sorption or uptake processes. Therefore, known additions (spikes) are often superficial and do not rigorously test an analytical method. In the Love Canal project, an attempt was made to develop laboratory control standards based on known additions of analytes to a common standard media, National Bureau of Standards (NBS) Standard Reference Material (SRM) 1645, river sediment. The SRM 1645 contains high levels of a number of organic compounds, but only a few that were on the Love Canal monitoring list, and none of the concentrations were certified by NBS. Furthermore, there does not exist a SRM containing certified low concentrations of appropriate analytes that could be used to measure limits of quantitation.

Disregarding the superficial nature of the known additions to NBS sediment, the analyses could have been used to calculate limits of detection except that the concentrations added were far too high to be applicable to the LOD procedure used for water analyses (Environmental Science and Technology, 1981, 1426). High level spikes, in the milligrams per kilogram range, were made because of the high levels of background in the SRM, and because of anticipated high levels of contamination in Love Canal samples. Under these circumstances, no measurements of limits of detection were possible.

Because modified Methods 608, 624, 625, and the metals methods are very similar to the methods used in water samples, except for the extraction of the sample, it is reasonable to estimate the limits of detection for soil/sediment/biota samples at the same order of magnitude as those calculated or estimated for the water samples. The limits of detection for water samples are given in Tables C-1, C-2, and C-3 in Appendix C, and are described and discussed in the section on "Limits of Detection/ Quantitation."

Method detection limits were not used to validate data in the Love Canal data base. Variability in quantitation and detection limits among laboratories is well known and unavoidable. Some laboratories may have quantified substances that others called "trace" or did not report the substances. These occurrences do not invalidate the results. At the worst, the method detection limits were probably several hundred micrograms per kilogram. Because the conclusions of the study were based on samples contaminated at several orders of magnitude or higher concentrations (that is, parts per million to parts per thousand), the magnitudes of the method detection limits had no affect on the overall conclusions of the study.

ANALYTICAL LABORATORY PERFORMANCE EVALUATIONS

In the soil, sediment, and biota media no specific performance evaluation (PE) samples were available. Therefore, the performance of the laboratories was evaluated using the samples described in Appendix C because: (1) the analytical laboratories conducting these analyses were often the same laboratories conducting water analyses; (2) the analytical methods were similar to water methods; and (3) the analyses were conducted over the same time period.

As pointed out in Appendix C, information from PE samples was not used to estimate precision and accuracy of the analytical measurements or to validate data for the Love Canal data base, because the PE samples were concentrates in an organic solvent that were added to reagent water by the analytical laboratory before the application of the method. Therefore, although the analytical laboratories were unaware of the true concentrations, they were aware that the samples were PE samples and may have taken unusual care in their analyses. The purpose of the PE samples was to discover problems with the execution of the methods and enable corrective action by the prime contractor on a timely basis.

For analytical laboratories analyzing soil, sediment, and biota samples, the PE samples in water did not, and could not, evaluate performance in the sample preparation parts of the soil/sediment/biota methods. However, because the remaining parts of the methodology were very similar (for example, the concentration, chromatography, and mass spectrometry), the PE samples served a useful purpose. In Table C-4 of Appendix C, a summary is presented of the percentage of acceptable PE results, by analytical method analyte group and analytical laboratory. In order to have an acceptable result, the analytical laboratory must have correctly identified the analyte and measured its concentration to within the acceptance limits specified by the Quality Assurance Branch, EMSL-Cincinnati. The performance of the laboratories in identifications was generally excellent, with very few analytes missed. The unacceptable results in Table C-4 were largely due to concentrations measurements outside the acceptable range. One laboratory shown in Table C-4 (SWRI), analyzed only soil and sediment field samples and no water field samples. As noted previously under methods selected for analysis of water samples, Method 625 employed the relatively new fused silica capillary columns, and there was initially some difficulty in adjusting to this in some laboratories. The PE samples served to assist in this adjustment and to provide data on the applicability of the columns. The performance evaluation results confirmed that the analytical laboratories were qualified users of the methodology.

It should also be noted that there was an attempt to prepare PE samples in a solid matrix by known additions of organic analytes to a common material, the National Bureau of Standards Standard Reference Material 1645, river sediment. This effort was not successful because the samples were not homogeneous and the results could not be used.

SAMPLE PRESERVATION

Directions for sample preservation were included in the analytical methods referenced previously. For the modified organic compounds methods (608, 624, and 625), preservation requirements included shipment and storage of samples in iced or refrigerated containers. There was a very high degree of compliance with these preservation requirements.

Maximum sample holding times prior to analysis were also specified in the methods, and were based typically on the water samples holding time requirements. There was a relatively high percentage of samples that were not analyzed within the specified holding times because the magnitude of the analytical requirements of the Love Canal study, plus numerous other ongoing environmental studies, literally overwhelmed the national capacity for low-level chemical analyses. The situation was especially prevalent with regard to the organics analyzed using modified Methods 624 and 625, which employ state-of-the-art gas chromatography/mass spectrometry technology, and Method 608. An analysis of the holding times revealed that most modified Method 608 and modified Method 625 samples were extracted within the 7-day holding time, and analyzed within the 30-day extract holding time. However, most modified Method 624 samples were held longer than the 14-day holding time. It should be noted, however, that the applicability of this 14-day holding time limit to soil and sediment samples analyses using modified Method 624 was not known empirically.

A study was undertaken by EMSL-Cincinnati to determine the effects of prolonged sample holding times on the stability of modified Method 624 analytes. Four modified Method 624 samples that had been analyzed, and then held for 97 days at 4°C and protected from light (which was considerably longer than the longest holding time period), were reanalyzed. Only one sample gave some evidence of losses of benzene and toluene. The conclusion was that for samples stored from 1 to 60 days before analysis according to the instructions in the methods, there was probably no significant losses of volatile analytes. Therefore, no samples were invalidated because holding times were exceeded.

DATA VALIDATION PROCEDURES

Validation means the rejection of certain analytical results whenever there was compelling evidence of systematic errors in sampling, preservation, or analysis associated with those results. Data validation for soil, sediment, and biota samples was rendered particularly difficult because there was so little experience with the methods. Furthermore, there was either little (or no) single laboratory or multilaboratory performance data, or precision and accuracy data. Therefore, lenient validation standards were established that were based on general principles, and very few samples were invalidated. For soil samples, a total of nine samples were rejected by the data validation process, where obvious errors in methods execution were observed. For sediment and biota samples, seven samples each were rejected; again, for obvious errors in methods execution. With all these media, it was reasoned that it was better to employ conservative invalidation criteria (leading to but few rejections of results), rather than risk losing potentially valuable information because of insufficient experience with the methods.

Modified Methods 624 and 625 with Soil and Sediment

For these methods the principal validation tool was a series of quality control compounds, often called surrogate analytes, that were added to each sample. The compounds selected as surrogates were valid method analytes that were neither commercially produced nor naturally occurring. Therefore, it was highly unlikely that any of them would be found in any environmental sample. The compounds are shown in Table D-1 along with the multilaboratory mean percentage recoveries, relative standard deviations, and acceptance limits. Analytical laboratories reported the quantities added (true values) and the amounts measured. Statistical acceptance limits were computed by EMSL-Las Vegas, but were used carefully because of the previously mentioned uncertainties associated with making known additions to solid matrices.

As was mentioned in the section on Limits of Detection/Quantitation, it is very difficult to add a known amount of an analyte or analytes to a soil, sediment, or biota sample and simulate the natural sorption or uptake processes. Therefore, known additions (spikes) are often superficial and do not rigorously test an analytical method. Alternatively, a spike may rapidly and (nearly) irreversibly sorb to a solid particle and the failure to recover it may not be indicative of laboratory performance. Therefore, recognizing the limitations of the methods, a sample was accepted as valid if at least one of the two to four surrogates used in the sample was reported in agreement with the acceptance limits in Table D-1. A minimum surrogate recovery of 1 percent was often considered acceptable, but occurred rarely. Only one of 452 samples analyzed by modified Method 624 was invalidated. With modified Method 625, 15 samples were invalidated; 13 of these samples were from CMTL. In all cases, these samples were invalidated because surrogates were either not reported or recoveries were so high that major method execution errors were suspected.

Laboratory Contamination

Methylene chloride was the solvent used in modified Method 625, and it was an analyte in modified Method 624. Methylene chloride was reported as the only analyte in a large number of

TABLE D-1. SUMMARY STATISTICS AND ACCEPTANCE LIMITS FOR MODIFIED METHOD 624 AND MODIFIED METHOD 625 SURROGATES FROM ALL LABORATORY MEASUREMENTS

Surrogate Analyte	Sample Type	Mean Recovery (Percent)	Relative Standard Deviations (Percent)	Acceptance Limits (Percent)
Method 624--modified				
Carbon tetrachloride-^{13}C	soil	99	26	47-151
Carbon tetrachloride-^{13}C	sediment	82	33	28-136
1,2-Dichloroethane-D_4	soil	68	29	28-108
1,2-Dichloroethane-D_4	sediment	67	15	47-87
Toluene-D_8	soil	97	13	72-122
Toluene-D_8	sediment	102	17	68-136
4-Chlorotoluene-D_4	soil	87	23	47-130
4-Chlorotoluene-D_4	sediment	81	28	35-127
Fluorobenzene	soil	93	14	68-118
4-Bromofluorobenzene	soil	95	4.2	87-103
Method 625--modified				
Hexachlorobenzene-$^{13}C_6$	soil	56	64	1-128
Hexachlorobenzene-$^{13}C_6$	sediment	46	89	1-128
Tetrachlorobenzene-$^{13}C_6$	soil	51	55	1-107
Tetrachlorobenzene-$^{13}C_6$	sediment	68	56	1-144
4-Chlorotoluene-D_4	soil	21	119	1-71
4-Chlorotoluene-D_4	sediment	41	56	1-87
Pentachlorophenol-$^{13}C_6$	soil	22	112	1-76
Pentachlorophenol-$^{13}C_6$	sediment	37	103	1-113
2-Fluorophenol	soil	57	54	1-119
1-Fluronaphthalene	soil	69	62	1-155
4,4'-Dibromooctofluorobiphenyl	soil	62	60	1-136
Nitrobenzene-D_5	sediment	48	67	1-112
Phenol-D_6	sediment	47	70	1-113

reagent and field blanks, and in many modified Method 624 samples it was the only analyte detected. This evidence strongly suggested the occurrence of laboratory contamination which was not unexpected with such highly sensitive analytical methodology. Therefore, although a few reports of methylene chloride may have been valid, the overwhelming number were very likely laboratory contaminants and it was impossible to distinguish the former from the latter. Therefore, all reports of methylene chloride in modified Method 624 samples were deleted from the data base to maintain the integrity of the study.

Late in the data reporting period, after this methylene chloride problem was discovered, one of the laboratories was inspected by EPA personnel. A large opening was found in the laboratory between the area where the methylene chloride extractions were conducted and the room where the analytical instrumentation was located. This finding supported the strong probability that methylene chloride was a laboratory contaminant in at least one of the laboratories.

Di(2-ethylhexyl)phthalate is a plasticiser used in the formulation of many plastic articles common to analytical laboratories, and was detected in widely varying amounts in both reagent blanks and field blanks. Therefore, all reports of this compound were judged highly unreliable and all reports were removed from the validated data base.

Modified Method 608 with Soil and Sediment

For this method the principal validation tool was the requirement that a laboratory control standard was to be analyzed with each batch of samples processed in a group at the same time. A laboratory control standard (LCS) was a known addition of three method analytes to a common matrix, the previously discussed NBS SRM river sediment 1645. The uncertainties associated with known additions to solid matrices, which were discussed in the previous section, were also applicable to this method. The three analytes were heptachlor, aldrin, and dieldrin, which are chlorinated hydrocarbon pesticides. Recoveries of these from the LCS matrix averaged 77 to 101 percent, depending on the laboratory, and the acceptance limits were in the range of 20 to 150 percent. No samples were invalidated by this procedure.

Modified Method 608 employs an electron capture gas chromatographic detector, and is subject to false positive identifications. In order to minimize these, two column confirmation and gas chromatography/mass spectrometry (GC/MS) confirmations were required for all modified Method 608 results. However, GC/MS confirmation was limited by the difference in detection limits between the methods. Users of the Love Canal data should be aware of the probability that low level, less than 0.5 micrograms per kilogram, measurements by modified Method 608 were not confirmed by GC/MS.

Metals in Soil and Sediment

As with modified Method 608, laboratory control standards (LCS) consisting of known additions (spikes) to the common matrix, NBS SRM river sediment 1645, were required. Again, the uncertainties of the spiking procedure were present. The NBS sediment contained metals analytes, but did not contain the four Love Canal analytes barium, beryllium, selenium, and silver. Therefore, known additions were required, and some known additions to real Love Canal samples were included in the quality assurance program. Each laboratory analyzed 10 LCS samples initially, then another LCS or a spike of a Love Canal sample for every 10 environmental samples. The laboratories were required to measure the background levels first and subtract these from the spike concentrations before the percentage recoveries were computed.

An overall mean recovery was calculated for each metal using the results from all laboratories. The means were in the range of 82 to 112 percent generally, the only exceptions being 64 percent for antimony and 77 percent for selenium in laboratories analyzing soil samples. A mean standard deviation of 18.5 percent of the mean recoveries was calculated for all laboratories, all metals, and both sample types (soil and sediment). Two times this standard deviation or 37 percent was used as the acceptance criterion for LSC samples and known additions to Love Canal samples. If any given measurement of any metal in an LCS or sample spike exceeded the limit of the metal's overall mean recovery plus or minus 37 percent, that metal measurement was invalidated in all samples associated with the particular LCS or sample spike. Thus, a sample could have an invalid recovery for one or several metals but be valid for the remainder of the metals. A total of 49 individual metals measurements were invalidated with more than 90 percent of the occurrences involving antimony, arsenic, selenium, and silver.

Method 625 Analytes in Biota

Only a minimal data validation effort was made for the reasons given in the section entitled, "Methods Selected for Analysis of Biota Samples," and very few samples were invalidated. However, isophorone was identified as a possible artifact created by the use of acetone during extraction of samples. Suspicions were aroused when this compound was found in many biota samples but not in any soil and in only one sediment sample. The GCA Corporation was requested to investigate this problem. Their report indicated that soxhlet extraction with acetone under certain pH conditions can result in the formation of several condensation products such as mesityl oxide, phorone, and isophorone. Considering that diacetone alcohol, mesityl oxide, and phorone were identified in the extracts, and the half-life of isophorone in the environment is approximately 1 month, and therefore not likely to have persisted in the environment over the period since the Love Canal landfill was closed, it was concluded that isophorone was an analytical artifact. Because of these reasons, isophorone in biota samples was removed from the Love Canal data base. It is not certain, of course, that the half-life of isophorone is or is not so short when stored in biological tissues.

Metals in Hair and Vegetation

The same data validation procedures described for metals in soil and sediment were employed for metals in hair. A total of 48 individual measurements (26 for mice, 22 for dogs) were invalidated; virtually all occurrences involved copper.

The National Bureau of Standards SRM orchard leaves was used as the laboratory control standard for the single laboratory that measured metals in vegetation. The criteria for validation were the same as described under soils and sediments, but all results for antimony, beryllium, chromium, and selenium were invalidated because all LCS samples gave zero percent recoveries.

ESTIMATES OF DATA PRECISION

The purpose of the field triplicate samples described at the beginning of the data validation section in Appendix C was to establish interlaboratory and intralaboratory precision. In addition, some methods required taking two aliquots of 10 percent of the samples to obtain further information about intralaboratory precision. However, a high percentage of the total samples gave all analytes below detection limits, and insufficient information was available to estimate the precision of the measurements from these samples.

Data precision may be estimated using the results of the measurements of the laboratory control standards (LCS) that were described in the section entitled "Limits of Detection/Quantitation." It should be noted that this is a less desirable approach than using field triplicate samples, because the LCS measurements do not include the variability associated with sampling, transportation, storage, and preservation of samples. Also these data may have been obtained over a period of weeks by some laboratories, and the values may include week-to-week variations that may significantly exceed variations within a given analysis day. Nevertheless, lacking the information from the replicate field samples, the LCS measurements may be used to provide rough estimates of data precision.

Table D-2 shows the relative standard deviations for replicate measurements of modified Method 624, modified Method 625, and modified Method 608 analytes in LCS samples. Note that summary statistics are reported in the table only when at least three replicate measurements were available. Some laboratories

TABLE D-2. RELATIVE STANDARD DEVIATIONS (RSD) FOR ORGANIC ANALYTES IN LABORATORY CONTROL STANDARDS NBS SEDIMENT

Analyte	Analytical Laboratory Code				
	ACEE	CMTL	GSRI	SWRI	EMSL-Cin
Method 624--modified					
Benzene	16	16	47	16	5.8
Toluene	11	14	10	13	5.3
Chlorobenzene	14	15	19	14	13
Method 625--modified					
2-Chlorophenol	45	--	105	31	--
4-Chloro-3-methylphenol	58	117	117	44	--
Pentachlorophenol	37	--	123	68	--
4-Nitrophenol	58	--	--	114	--
1,4-Dichlorobenzene	48	--	77	67	--
N-nitrosodi-n-propylamine	65	--	114	28	--
1,2,4-Trichlorobenzene	60	--	81	35	--
2,4-Dinitrotoluene	77	--	103	55	--
Di-n-butylphthalate	19	--	87	24	--
Pyrene	53	--	121	--	--
Benzo(a)anthracene	84	--	--	--	--
Benzo(b)fluoranthene	62	--	--	--	--
Benzo(a)pyrene	48	--	--	--	--
Indeno(1,2,3-cd)pyrene	69	--	--	--	--
Benzo(g,h,i,)perylene	58	--	--	--	--
Method 608--modified					
Heptachlor	14	15	45	11	--
Aldrin	61	16	20	12	--
Dieldrin	37	29	19	8.3	--
Aroclor 1242	--	--	58	--	--

did not analyze a sufficient number of some types of samples to accumulate the minimum required number of LCS measurements to justify computing summary statistics. The precision of any single measurement in the Love Canal data base at the 95 percent confidence level may be estimated using the formula:

Analytical Result ± 1.96 x (RSD from Table D-2).

The RSD should be selected from Table D-2 according to the analyte measured and the laboratory analyzing the sample. If the exact analyte is not in Table D-2, a structurally similar analyte may be used; for example, if the analyte of interest is 2-nitrophenol, the RSD for 4-nitrophenol may be used. If RSD data for a reporting laboratory of interest is not in Table D-2, use

TABLE D-3. RELATIVE STANDARD DEVIATIONS (RSD) FOR METALS ANALYTES IN LABORATORY CONTROL STANDARDS NBS SEDIMENT

	Analytical Laboratory Code		
Analyte	ERCO	PJBL	SWRI
Arsenic	12	47	10
Antimony	9.4	79	74
Barium	9.4	44	12
Beryllium	7.3	19	8.7
Cadmium	3	7	2
Chromium	8.8	27	12
Copper	2	25	13
Lead	7	32	3
Mercury	17	18	9
Nickel	3.1	15	6.4
Selenium	7.2	51	4.6
Silver	4.7	13	39
Thallium	4	28	7.2
Zinc	4.9	16	3

the mean RSD of all laboratories reporting that analyte. For metals and anions a similar estimate may be made using the data in Table D-3.

Precision estimates were not used to validate data for the Love Canal data base. Data validation procedures are explained in detail in the previous section entitled, "Data Validation Procedures."

ESTIMATE OF DATA ACCURACY

Data from modified Methods 624, 625, and 608 for organic analytes probably have a significant bias, but this cannot be estimated because suitable standard reference materials were not available. The limitations of using known additions for this purpose were explained in detail previously.

For metals measurements several SRMs were available, but they did not contain all the analytes of interest. Table D-4 shows the mean percentages of the NBS certified values in SRM river sediment 1645 observed by the analytical laboratories, and the computed standard deviations. These values were not used directly to validate data for the Love Canal data base, but do indicate

TABLE D-4. MEAN PERCENT RECOVERIES AND STANDARD DEVIATIONS OF NBS CERTIFIED VALUES IN SRM RIVER SEDIMENT 1645

	Analytical Laboratory Code					
	ERCO		PJBL		SWRI	
Analyte	Mean	S.D.	Mean	S.D.	Mean	S.D.
Arsenic	103	11	113	55	66	16
Antimony	47	43	112	64	6	6
Cadmium	84	8	90	15	89	4
Chromium	105	7	78	5	105	9
Copper	99	5	94	2	91	4
Lead	102	8	86	12	93	4
Nickel	90	12	90	13	68	10
Thallium	--	--	104	--	93	80
Zinc	96	6	78	4	92	2

S.D.: Standard Deviation

the difficulties encountered in the measurement of arsenic, antimony, and a few other elements at some laboratories. As indicated previously, measurements of these elements were selectively invalidated. For most of the other elements there was no significant bias in the metals measurements in river sediment.

SUMMARY OF MAJOR ACTIONS TAKEN AS A RESULT OF GCA'S QUALITY ASSURANCE FUNCTION

The activities of the prime contractor in the day-to-day quality assurance program are described in detail in the GCA QA/QC summary report on the Love Canal study. The purpose of this section is to briefly summarize major actions by the GCA Corporation.

The prime contractor routinely discussed, by telephone and during site visits, the results of the external quality assurance samples with the analytical laboratories. Requirements for corrective action were provided during these discussions. The prime contractor also monitored the results from the internal quality assurance program, and discussed these with the analytical laboratories during telephone conversations and site visits. Again, requirements for corrective action were provided.

One significant action that resulted from the day-to-day quality assurance program was the removal of the PJBL laboratory from the analyses of samples by modified Method 625 in soils and sediment. During a site visit and during discussions of the internal and external quality assurance samples, it was discovered that PJBL was using packed columns with modified Method 625, and did not have the capability to analyze the samples with the fused silica capillary columns. Consequently, all previous results using modified Method 625 provided by PJBL were removed from the Love Canal data base, and work on modified Method 625 was suspended at PJBL. Eventually, PJBL developed the capability to use the fused silica capillary columns and all the extracts were reanalyzed. Details of this incident and other activities of the prime contractor are given in the GCA Corporation QA/QC summary report referenced previously.

APPENDIX E
QUALITY ASSURANCE FOR AIR SAMPLES

OVERVIEW OF QUALITY ASSURANCE PROGRAM

It was recognized during the early planning stages of the study that a comprehensive quality assurance (QA) effort would be required to support the Love Canal monitoring program. Consequently, QA procedures were developed and implemented as an integral part of the program. This appendix summarizes the quality assurance efforts for the air portion of the Love Canal monitoring study. Detailed descriptions of the quality assurance and quality control (QA/QC) procedures used during the collection and analysis of air samples are contained in the previously referenced Quality Assurance Plan, Love Canal Study, LC-1-619-206 compiled by the GCA Corporation, and available from NTIS. Appendix A to the quality assurance plan describes the sampling procedures, Appendix B describes the analytical procedures, and Appendix Q describes the QA plans submitted by the subcontractors used in this program. A more detailed discussion of the QA/QC results of the prime contractor's (GCA Corporation) and the subcontractors' quality assurance efforts is contained in Love Canal Monitoring Program, GCA QA/QC Summary Report, available from NTIS. A listing of compounds and metals to be identified quantitatively or qualitatively by each method of analysis is given in Appendix A, Table A-2.

Because the methodologies selected for use in Love Canal air analyses had not yet been used routinely in monitoring networks, the quality assurance program was designed to minimize variability in the data and to fully document the precision and accuracy of the measurements performed during the Love Canal study. In order to accomplish these goals, the air monitoring and quality assurance programs were designed by EPA and performed under contract by the prime contractor and the sampling and analysis subcontractors. The contracts specified the methods of sampling and analysis, including quality control steps to be used by the subcontractors, and emphasized the importance of quality assurance by requiring the submittal and approval by EPA of an acceptable quality assurance plan. The format and content of minimally acceptable quality assurance plans was developed by EPA and specified in writing in each subcontract.

In addition to the required QA plans, the following elements were included in the design of the Love Canal study that were intended to minimize measurement variability.

1. Equipment used to collect air samples was supplied by EPA. The equipment had been used previously to collect air samples similar to those collected at Love Canal. The equipment was verified to be in working order prior to shipment.

2. Only one subcontractor was responsible for the collection of air samples. As a result, all required sampling procedures were consistently applied across all sampling sites.

3. Materials used to collect air samples were manufactured from a single lot and supplied to the field sites. Both TENAX tubes and polyurethane foam (PFOAM) plugs were cleaned by a single subcontractor and verified by EPA as being acceptable for use prior to their being used for field sampling, calibration standards samples, calibration check samples, field blanks, or blind audit quality assurance samples. High-volume (HIVOL) filters from the batch used in the SLAMS monitoring network were used at Love Canal.

4. TENAX calibration check samples were prepared by a single subcontractor, and PFOAM calibration check samples were prepared by EPA. These samples were subsequently supplied to each analytical subcontractor. Evaluation of analytical performance during the Love Canal study was based on common samples analyzed by each laboratory.

5. Common calibration samples were supplied to all laboratories analyzing TENAX tubes.

6. The use of laboratory control charts to monitor measurement system variability and maintain acceptable performance was required. Initial control chart limits for TENAX measurements were specified based on an estimate of expected performance recommended by an experienced, independent laboratory not involved in the Love Canal study. The actual results obtained from the analysis of calibration check samples, however, were used to subsequently establish control limits that were applicable directly to the laboratories performing the analyses.

Prior to initiation of the monitoring and analysis efforts it was realized that 1 or 2 months might elapse before EPA would receive data that had been subjected to all of the required quality control checks and verifications. Because of the length of time that might elapse, it was apparent that timely corrective actions for problems which were uncovered would be precluded. Therefore, EPA required, as part of the external QA program, the analysis of sufficient numbers of calibration check samples and blind audit samples to allow classification of the precision and accuracy of subcontractor measurements, which was independent of the quality control efforts of the sampling and analysis laboratories. Because this extensive external program existed, EPA retained the responsibility for final validation of the analytical results, and determination of the precision and accuracy of the air measurements performed at Love Canal.

Carrying out the monitoring effort at Love Canal was the responsibility of the prime contractor. As part of their efforts they:

1. Coordinated the distribution of samples to the field sampling sites and subsequently to each analytical subcontractor.
2. Inserted external quality control samples (blanks, blind audit samples, etc.) into the normal shipments of field samples in a manner such that they could not be identified as control samples by analytical laboratories.
3. Supplied calibration and calibration check samples to the analytical laboratories.
4. Maintained the day-to-day overview of the sampling, analysis, and quality control efforts of the subcontractors through review of data received, and by conducting inspections at the subcontractor laboratories.
5. Performed the initial verification of data transmitted to EPA to assure that the reported analytical results were those actually obtained.

More detailed descriptions and discussions of the GCA Corporation QA/QC efforts are contained in the previously mentioned document (Love Canal Monitoring Program, GCA QA/QC Summary Report), and are summarized in the last section of this Appendix.

In order to obtain consultation and advice from an independent group, the QA plans and results of the Love Canal study were reviewed by the sampling protocols study group of EPA's Science Advisory Board. Their review was conducted during the design, study, and data evaluation phases of the project.

The remainder of this Appendix describes the external quality assurance program and presents the estimates of data precision and accuracy for the air samples collected at Love Canal.

METHODS SELECTED FOR ANALYSIS OF AIR SAMPLES

The volatile organic compounds were collected by sorbtion onto a TENAX cartridge, thermally desorbed, and analyzed by gas chromatography/mass spectrometry (GC/MS). The method used for collecting and analyzing volatile organics in air represents the latest application of research developments in this field. This method was used because it was the only known technique that would provide information (at a reasonable cost) on a wide variety of volatile organics in air, could be used in a routine network operation, and was available at the time required for performing the Love Canal study. The methodology was based on the work performed by E. D. Pelizzari of Research Triangle Institute for EPA and other federal agencies. (See References 1 through 7).

Pesticides and related compounds (subsequently referred to as pesticides in the remainder of this Appendix) were collected on polyurethane foam plugs (PFOAM). PFOAM collectors were analyzed by Soxhlet extraction, followed by sample concentration and gas chromatography. High performance liquid chromatography was used for the analysis of chlorinated phenols. The methodology for PFOAM collection of pesticides was developed, in part, by the Analytical Chemistry Branch, HERL-RTP. (See References 8 through 14). This sample collection methodology also represented the latest application of research developments in the field. The method employed has been extensively tested at HERL-RTP for compounds of interest, and was deemed the most efficient and cost-effective means available for monitoring pesticides and related compounds at Love Canal. The PFOAM procedure was a valuable complement to TENAX, because it was used to collect and analyze for those less volatile compounds that do not thermally desorb efficiently from TENAX for GC/MS determination.

The methodology used to collect air particulate samples (HIVOL) for metals analyses was the Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method) Code of Federal Regulations (CFR), Title 40, Part 50, Appendix B. HIVOL filters were extracted with an acid mixture and most metals were analyzed by an Inductively Coupled Argon Plasma Optical Emission Spectrometer (ICAP) technique. Arsenic, cobalt, and chromium were analyzed by a Neutron Activation Analysis (NAA) procedure, directly using the HIVOL filters. These methods have been used routinely to analyze samples collected in the EPA National Air Surveillance Network (NASN). The precision and accuracy of these methods have been documented during their use in NASN (unpublished data are available from the Environmental Monitoring Division, EMSL-RTP).

SELECTION OF ANALYTICAL SUBCONTRACTORS

Because the methodologies for analysis of volatile organics and pesticides were relatively new, no detailed history of performance of potential analytical subcontractors was available. In order to acquire an estimate of the capabilities of the analytical community, a short analytical performance evaluation exercise was conducted before awarding the analytical contracts for the Love Canal study. Interested organizations were invited to Love Canal to collect and analyze volatile organic compounds and pesticides at a common site. In addition to the field samples, spiked quality assurance (QA) samples were supplied to each participant in this performance evaluation. The results of the analyses of the QA and field samples were used to judge the analytical capabilities of potential subcontractors and eliminate poor performers from further consideration. Final subcontractor selection was also based on the number of samples that the subcontractor could analyze during the project period, and the cost of such analyses.

The metals analyses were all performed by the Environmental Monitoring Division, EMSL-RTP, using techniques employed on the NASN samples. Because a history of performance was available, no pre-Love Canal performance evaluation analyses were required.

LIMITS OF DETECTION/QUANTITATION

Because the methods for collecting and analyzing volatile organic compounds and pesticides are still undergoing evaluation as to precision, accuracy, sensitivity, and other parameters, each analytical subcontractor was asked to provide estimates of their limit of detection (LOD). A limit of quantitation (LOQ), based on estimated detection limits, was selected by EPA for each type of analysis, so that all analytical subcontractors would be reporting results in the same range. For the parameters being quantified on TENAX, it was decided that values above 50 nanograms per sample (ng/sample) would provide meaningful quantitative results; for pesticides samples, quantitative results were reported when compounds were above 90 micrograms per plug (μg/plug). Samples yielding measurement signals that were above the detection limit but below the quantitation limit were assigned the value trace. As part of the monitoring program, a number of targeted organic compounds were also to be identified whenever present in a sample, but not quantified. When these compounds were identified in a sample at levels above the contractor supplied estimated limit of detection they were labeled "qualitative." All concentrations reported for TENAX and PFOAM analyses are reported in units of micrograms per cubic meter ($\mu g/m^3$). The estimated limits of detection and quantitation for each parameter analyzed in the air samples are presented in Tables E-1 (TENAX) and E-2 (PFOAM).

TABLE E-1. VOLATILE ORGANICS ON TENAX

	Detection/Quantitation Limits (ng/tube)			
	BCL		PEDCo	
Compound	D	Q	D	Q
Benzene	5	50	3	50
Carbon tetrachloride	5	50	20	50
Chlorobenzene	5	50	5	50
o-Chlorotoluene	5	50	4	50
p-Chlorotoluene	5	50	4	50
1,2-Dibromoethane	5	50	13	50
o-Dichlorobenzene	5	50	7	50
p-Dichlorobenzene	5	50	7	50
1,1,2,2-Tetrachloroethylene	5	50	15	50
Toluene	5	50	6	50
1,2,3-Trichlorobenzene	5	50	NA	NA
1,2,4-Trichlorobenzene	5	50	NA	NA
1,3,5-Trichlorobenzene	5	50	NA	NA
Chloroform	5	Qual.	20	Qual.
1,2-Dichloroethane	5	Qual.	15	Qual.
2,4-Dichlorotoluene	5	Qual.	7	Qual.
o-Chlorobenzaldehyde	5	Qual.	25	Qual
p-Chlorobenzaldehyde	5	Qual.	25	Qual.
Benzyl chloride (α-Chlorotoluene)	5	Qual.	25	Qual.
1,1-Dichloroethane	5	Qual.	7	Qual.
1,1-Dichloroethylene	5	Qual.	15	Qual.
1,2-Dichloroethylene	5	Qual.	15	Qual.
Dichloromethane	5	Qual.	15	Qual.
Phenol	5	Qual.	30	Qual.
o-Xylene	5	Qual.	5	Qual.
m-Xylene	5	Qual.	5	Qual.
p-Xylene	5	Qual.	5	Qual.

NA: Not analyzed
Qual.: Only qualitative reporting required

TABLE E-2. PESTICIDES ON FOAM PLUGS

Compound	Detection/Quantification Limits (μg/plug)			
	GSRI		SWRI	
	D	Q	D	Q
Lindane	30	90	45	90
Hexachlorobenzene	30	90	45	90
Hexachlorocyclopentadiene	30	90	45	90
1,2,3,4-Tetrachlorobenzene	30	90	45	90
1,2,3-Trichlorobenzene	30	90	45	90
1,2,4-Trichlorobenzene	30	90	45	90
1,3,5-Trichlorobenzene	30	90	45	90
2,4,5-Trichlorophenol	30	90	45	90
Pentachlorobenzene	30	90	45	90
Hexachloro-1,3-butadiene	30	Qual.	45	Qual.
1,2,4,5-Tetrachlorobenzene	30	Qual.	45	Qual.
α,α,2,6-Tetrachlorotoluene	30	Qual.	45	Qual.
Pentachloro-1,3-butadiene	30	Qual.	45	Qual.
Pentachloronitrobenzene	30	Qual.	45	Qual.
1,2,3,5-Tetrachlorobenzene	30	Qual.	45	Qual.
α-BHC	30	Qual.	45	Qual.
Heptachlor	30	Qual.	45	Qual.

Qual.: Only qualitative identification required

Limits of detection for the metals analyses had been determined over a period of time by EMSL-RTP prior to the Love Canal study. These limits are based on analyses of HIVOL filter blanks and are presented in Table E-3. Because only one laboratory analyzed samples for metals, quantitative results were reported whenever the value was above the limit of detection.

In order to verify limits of detection and to establish background levels for the TENAX analyses, blank sample tubes were analyzed throughout the study by the subcontractors. Cleaned blank TENAX sample tubes were sealed and sent to the field sites. The tubes were returned unopened to the analytical laboratories for analysis. The analysts were unable to distinguish these field blanks from normal samples. The analytical results for these field blanks are shown in Table E-4. The mean and standard deviation reported in Table E-4 are for those samples where concentrations were above the limit of quantitation (50 ng).

TABLE E-3. DETECTION LIMITS FOR INORGANICS (HIVOL SAMPLES)

Element	μg/sample
Antimony	26.5
Arsenic	16.2
Beryllium	0.332
Cadmium	0.955
Chromium	22.2
Copper	10.5
Lead	28.2
Nickel	2.56
Zinc	353.0

TABLE E-4. RESULTS FROM ANALYSES OF BLANK TENAX SAMPLES[†]

Compound	Number of Samples With Quantifiable Amounts	Number of Samples Listed as Trace	Mean[‡]	Standard Deviation[‡]
Benzene	18	108	3.10	1.31
Toluene	31	82	8.20	6.90
1,1,2,2-Tetrachloroethylene	62	40	6.17	5.08
Carbon tetrachloride	2	1	3.60	0.92
Chlorobenzene	0	1	--	--
o-Chlorotoluene	0	0	--	--
p-Chlorotoluene	0	0	--	--
1,2-Dibromoethene	0	1	--	--
o-Dichlorobenzene	0	1	--	--
p-Dichlorobenzene	0	0	--	--

[†] A total of 132 blank samples were analyzed.

[‡] Units are μg/m^3 and are based on samples with quantifiable amounts only.

Benzene, toluene, and 1,1,2,2-tetrachloroethylene were reported as present in the vast majority of blank TENAX tubes (for example, benzene results were reported at concentrations above the detection limit in 126 of the 132 blanks). All laboratories identified these compounds as being present. The quantifiable results for toluene, however, came mostly from one laboratory (29 of the 31 quantifiable results). Consideration of the levels and variability of benzene, toluene, and 1,1,2,2-tetrachloroethylene found in the blanks should be made in any interpretation of the air TENAX results. Toluene and benzene are known normal contaminants of TENAX, and their presence at low levels was expected. An inspection of the facility used for cleaning and preparing the TENAX prior to field sampling indicated that 1,1,2,2-tetrachloroethylene could have been introduced as a contaminant at that time.

Analysis of the field data for the compounds benzene, toluene, and 1,1,2,2-tetrachloroethylene must take into account the probability that a single result could have been caused by contamination on a blank tube. To be relatively certain that an obtained single value was not due to blank contamination, the field concentration should be greater than two standard deviations above the mean values reported in Table E-4 for these three compounds. While it is true that values of benzene, toluene, and 1,1,2,2-tetrachloroethylene that are just above the stated quantitation limits could be attributed to blank contamination, the higher levels monitored at Love Canal should not have been caused by such contamination. No adjustments for contamination were made in reported TENAX analyses.

Analyses of field blanks for the PFOAM and metals samples revealed no blank contamination was present. Therefore, values above the quantitation limits were probably not caused by blank contamination.

ANALYTICAL LABORATORY PERFORMANCE EVALUATIONS

In addition to the pre-award evaluation of potential analytical contractors, two types of performance evaluations were conducted during the Love Canal project. First, EPA performed audits at the beginning of the study of the flow rates of the samplers used for collecting air samples, in order to verify that the sample collection was being conducted properly. A team consisting of EPA personnel independently measured the flow rates of several samplers for each type of sampler (TENAX, PFOAM, and HI-VOL). The results of the audit (reported later under "Estimates of Data Accuracy") indicated excellent performance by the sampling contractor and no additional flow audits were conducted by EPA during the 3-month sample collection period. And second, analytical performance was evaluated on a continuing basis throughout the study. Blind performance evaluation (audit) samples were periodically sent to each analytical laboratory. These samples were prepared by an independent contractor (TENAX and metals) or by EPA (PFOAM) and inserted into the regular field samples by the GCA Corporation. The analyst was unable to distinguish these samples from the routine field samples. Results of the analysis of these audit samples are also discussed later in the "Estimates of Data Accuracy" section.

SAMPLE PRESERVATION

In order to ensure that valid samples were received at the analytical laboratories, several precautions beyond the normal chain-of-custody procedures were taken in the handling of certain air samples. First, TENAX and PFOAM samples were maintained at 4° C before and after sampling in order to minimize sample degradation. Second, it is known that the TENAX substrate tends to form artifactual benzene and toluene if left standing for long periods of time after cleaning. In order to circumvent this problem, TENAX samples were required to be analyzed within 30 days of final cleaning. Consequently, TENAX was cleaned in batches during the Love Canal Study, checked by EPA for purity, and shipped directly to Love Canal. Prudent actions by GCA Corporation personnel ensured that analyses were accomplished within the 30-day period. Third, in several instances clean TENAX tubes were removed from service prior to sample collection, because the GCA Corporation sample bank coordinator at Love Canal determined that analyses could not be performed within the 30-day period. And fourth, HIVOL samples were shipped in such a fashion that collected particles would not be lost from the filters, using procedures outlined in the EPA Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Section 2.2.

DATA VALIDATION PROCEDURES

For the volatile organic compounds analyzed from the TENAX samples, EPA incorporated a scheme for final data validation in the contractual requirements of the analytical subcontractors. Special standards, calibration check samples, were supplied to each analytical laboratory and were analyzed during the first 4 hours of each day's analytical activities, and periodically thereafter. These samples were supplied and analyzed in addition to calibration samples and other internal samples which were analyzed for quality control purposes. The samples were prepared by the TENAX quality assurance contractor using procedures described in References 2, 3, 5, and 6. The analytical subcontractor and GCA Corporation were supplied with true concentrations of these samples. Both the analytical subcontractor and GCA Corporation were to monitor the results of the analyses of these samples on a real-time basis in order to determine if the analysis process was in control. EPA also attempted to monitor these results during the analysis period, but results were usually received too late after the analysis in order for EPA to effectively alter poor performance on a real-time basis. The last section of this Appendix describes the nature of real-time corrective actions based on the GCA Corporation's monitoring of the results from calibration check samples.

EPA was, however, able to use the results from the analysis of the calibration check samples as its main data validation procedure. The results from the calibration check samples were plotted in a control chart format (percent difference from true value) after all results had been reported to EPA for each substance analyzed. The reported results were included from all analytical systems and the data analyzed as a whole. For each substance analyzed, $\pm 2\sigma$ limits were constructed about the mean percent difference, after prior removal of obvious outliers. On a day-to-day basis, the results from the calibration check samples were compared to the $\pm 2\sigma$ limits. When the majority of results on a particular day were found to exceed the limits for all substances in the calibration check samples, all results for that day were eliminated from the data. This procedure eliminated a total of 20 field samples of volatile organic data. Once these samples were removed, new $\pm 2\sigma$ and $\pm 3\sigma$ limits were constructed about the mean percent difference, again with the prior removal of any remaining outliers. The results from the blind performance audit samples were then compared to these limits to determine if further data should be invalidated. No additional data were identified for removal by the results from the blind audit samples.

As a final check, the absolute response on an internal standard spiked onto each field sample by the analytical subcontractor was inspected for consistency with those other samples that were analyzed immediately before and after it. Samples in which the response for the standard was an order of magnitude higher or lower than those surrounding it were also invalidated. This procedure resulted in the elimination of 11 more field samples, yielding a total of 31 samples invalidated by the external QA program for air TENAX analyses.

The procedure for validating PFOAM analyses was performed by analyzing the results of a single internal standard introduced into each Love Canal sample by the analytical subcontractor. The recovery efficiency of this sample spike indicated the expected accuracy of measurement for residues in each actual sample. Results for a sample were discarded if the recovery of the internal standard was less than 25 percent. The polyurethane foam sample results were further reviewed for validity and two other reasons for invalidating data were discovered:

1. Sample loss due to error in concentration step.
2. Sample mistakenly fortified with test compounds.

A total of 43 PFOAM samples were invalidated by these 3 procedures.

Metals data were validated from the analyses of the performance evaluation samples analyzed as blind unknowns, or from the analysis of National Bureau of Standards (NBS) Standard Reference Materials (SRM). The percent difference of the analytical result from the spike or true value was determined. The results are shown in the section "Estimates of Data Accuracy." No metals data were invalidated due to poor analytical performance.

ESTIMATES OF DATA PRECISION

To determine method precision, several field sites were selected for collocating samplers. One of the samplers was designated the official sampler for the site and the other was designated the duplicate sampler. The duplicate samples obtained were then carried through the analysis procedures in the normal manner. The analysts were unable to identify the samples as being duplicates. The concentration differences (duplicate minus official) between the results from collocated samples was used to estimate the precision of the monitoring data. Only validated data were used for the determination of precision.

Table E-5 reports the results from the collocated samples collected in this study for the air TENAX samples. During this study, a total of 98 valid pairs of duplicate samples were collected. Differences in $\mu g/m^3$ were calculated for each sample pair when both reported concentrations were above the limit of quantitation for the pollutant. At the $\alpha=0.01$ level of significance, none of the mean differences were significantly different from zero. The standard deviations presented in Table E-5 can be used to calculate precision estimates for the TENAX field data by means of the following formula:

$$\text{Field Results } (\mu g/m^3) \pm \frac{1.96 \ [\text{Std. Dev. from Table E-5 } (\mu g/m^3)]}{\sqrt{2}}.$$

No estimate of precision could be made from collocated samples for the metals or pesticide analyses because an insufficient number of duplicate results were obtained to yield meaningful comparisons. The variability of the estimates of accuracy, however, can be used to give an approximate estimate of precision for metals, pesticides, and those volatile organics which also had too few results from the collocated samples to estimate measurement precision. A percentage interval equal to twice the standard deviation of the percent difference can be used as an approximate estimate of data precision for the volatile and metals analyses, while twice the percent relative standard deviation can be used for pesticides and related compounds.

TABLE E-5. RESULTS FROM AIR TENAX DUPLICATE SAMPLES

Compound	Mean[†]	Standard Deviation[†]	Pairs[‡]
Benzene	0.15	2.99	52
Carbon tetrachloride	-1.05	--	1
Chlorobenzene	--	--	0
o-Chlorotoluene	0.60	0.63	3
p-Chlorotoluene	0.27	0.45	4
1,2-Dibromethane	--	--	0
o-Dichlorobenzene	-3.84	6.48	9
p-Dichlorobenzene	-1.31	1.01	5
1,1,2,2-Tetrachloro-ethylene	1.95	10.94	56
Toluene	0.32	10.53	43

[†] Units are $\mu g/m^3$

[‡] A total of 98 valid duplicate pairs of samples were collected. The number in this column represents the number of pairs where both results were quantifiable.

ESTIMATES OF DATA ACCURACY

It has been the established practice in air monitoring to estimate accuracy from independent audits of the measurement process (CFR 40, Part 58, Appendix A). An audit of the flow rates of the field samplers was made during normal sampling periods. The flow audits were conducted by EPA, and were independent of the routine flow measurements made by the sampling contractor. The difference between the contractor flow rate and the EPA determined flow rate can be used to estimate the accuracy of the sampler flow rate. The results of the flow audits are given in Table E-6.

In contrast to the standard procedure used to estimate the accuracy of TENAX measurements, EPA elected to determine accuracy from the results of the calibration check samples. This was done because the number of blind audit samples needed to establish accuracy over the analytical range would have approximately equaled the number of calibration check samples. Doubling the number of

TABLE E-6. RESULTS OF AUDITS OF SAMPLER FLOW RATES

Sampler Type	Percent Difference Mean	Percent Difference Standard Deviation	Number of Samplers Audited
TENAX	-1.8	2.5	31
Polyurethane foam	-4.1	1.8	36
High-volume	-4.3	6.3	8

quality assessment samples (from 300 to 600) was judged not to be the most cost-effective means of quantifying accuracy. Because the calibration check samples and the blind audit samples were prepared by the same contractor, the results from the check samples were expected to be similar to the results from the blind audit samples. Therefore, the percent difference between the spike value and the analytical result from the calibration check sample was used to estimate the accuracy of the analyses. The results of the analyses of all calibration check samples are summarized in Table E-7 for each of the substances that were quantified.

TABLE E-7. RESULTS FROM THE ANALYSES OF CALIBRATION CHECK SAMPLES (TENAX ANALYSES)

Compound	Percent Difference Mean	Percent Difference S.D.	Number of Samples
Benzene	-2.3	28.7	285
Carbon tetrachloride	-5.8	25.2	307
Chlorobenzene	-3.9	27.1	308
o-Chlorotoluene	0.0	25.9	298
1,2-Dibromoethane	-7.5	30.3	309
o-Dichlorobenzene	-1.2	25.4	309
1,1,2,2-Tetrachloroethylene	6.9	25.7	303
Toluene	-2.0	37.1	276

S.D.: Standard deviation

To corroborate the results from the calibration check samples, blind spike samples were periodically inserted into the field sample analyses. Results from the blind spike samples analyses fell within the $\pm 3\sigma$ (3 standard deviation) limits established from the analyses of the calibration check samples, thus confirming the estimates obtained from the check samples. The mean percent differences (Table E-7) were all less than ±10 percent. In other ambient air studies, the data are accepted as reported when biases are documented as less than ±10 percent.

To further corroborate the accuracy of the TENAX analyses, calibration check samples and blind audit samples were analyzed by an independent laboratory. Only a limited number of samples (nine) were analyzed by this laboratory during the Love Canal study resulting in 58 individual analytical results. Ninety-three percent of these results fell within the $\pm 2\sigma$ limits established from Table E-7, and all the results within the $\pm 3\sigma$ limits. Thus, the independent analyses also corroborated the accuracy estimates.

A further breakdown of the results of the analysis of the calibration check samples was also performed. The air TENAX calibration check samples were divided into three levels, and the four separate analytical systems that were used to perform the analyses. One system, however, was in operation only a few days and was not included in the statistical analyses. Table E-8 summarizes the analytical results for the air TENAX calibration check samples by analytical system, and by sample concentration level (in nanograms per sample). In Table E-8, the mean percent difference between the reported concentration and the true concentration, the standard deviation (S.D.) of this percent difference, and the number of samples analyzed is presented. Table E-9 gives the approximate concentrations of the three levels of calibration check samples used.

Accuracy estimates were made for polyurethane foam samples through analyses of two blind audit samples that accompanied each lot of field samples sent to the two analyzing laboratories. Two of the same samples were also returned to the EPA as blind samples for analysis by a senior chemist who was not involved with preparation of the QA samples. The primary purpose of this was to monitor any losses that might have resulted from the shipping and handling of the blind samples. The accuracy of analytical measurements made by the two laboratories was indicated by their qualitative and quantitative performance on these blind QA samples. Table E-10 provides a summary of the polyurethane foam blind check samples results for the two contractor laboratories and the EPA laboratory.

Analytical accuracy of ICAP metals analyses was also estimated from the results of analyses of audit samples. These samples were supplied as blind unknowns to the analytical laboratories. The results for ICAP metals accuracy are presented in

TABLE E-8. RESULTS OF ANALYSES OF CALIBRATION CHECK SAMPLES BY LEVEL AND ANALYTICAL SYSTEM[†]

		Level 1			Level 2			Level 3		
Compound	System	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
Benzene	1	9.40	40.77	30	8.61	28.72	29	-1.27	35.65	33
	2	-3.89	28.79	16	3.79	30.54	21	8.52	26.20	26
	3	-9.34	16.34	39	-7.50	21.87	47	-19.35	17.25	37
	ALL	-1.76	30.23	88	0.24	26.76	99	-5.21	29.13	98
Carbon tetrachloride	1	-5.62	27.60	30	-14.22	28.29	33	-14.48	33.08	33
	2	12.75	15.99	21	3.43	17.20	22	-0.79	29.45	30
	3	-16.27	16.48	41	-3.27	20.07	48	-1.08	20.93	39
	ALL	-6.26	23.00	96	-6.17	23.52	106	-4.91	28.78	105
Chlorobenzene	1	-4.05	34.52	32	1.16	27.85	32	-5.59	29.55	34
	2	13.69	21.78	21	8.36	32.14	22	8.01	32.30	29
	3	-15.67	17.14	41	-10.70	18.34	48	-10.63	15.79	39
	ALL	-5.92	27.91	98	-2.31	26.29	105	-3.46	27.17	105
o-Chlorotoluene	1	-3.97	26.50	29	2.07	31.59	29	-4.98	25.88	32
	2	11.60	23.31	21	4.71	25.02	21	12.23	33.04	29
	3	-8.71	20.32	40	-3.11	22.32	48	0.57	22.14	39
	ALL	-3.05	24.39	94	0.75	25.83	101	2.10	27.13	103
1,2-Dibromoethane	1	0.91	31.94	30	0.34	33.03	33	-11.35	33.10	35
	2	20.32	26.00	21	3.80	26.05	22	11.08	35.80	30
	3	-30.08	13.99	41	-18.56	18.69	48	-14.65	21.66	39
	ALL	-9.35	31.59	96	-7.49	27.69	106	-5.92	31.82	107
o-Dichlorobenzene	1	-9.15	26.36	32	3.71	29.31	32	1.21	28.95	34
	2	10.95	19.93	21	9.44	28.45	22	11.31	28.24	30
	3	-6.76	22.67	41	-7.90	19.12	48	-8.33	15.20	39
	ALL	-3.78	25.41	98	-0.10	25.43	105	0.19	25.50	106
1,1,2,2-Tetrachloroethylene	1	4.17	27.49	28	7.52	31.73	33	6.73	28.67	34
	2	21.56	16.35	21	6.56	22.10	22	7.76	28.29	30
	3	16.20	30.12	39	4.94	20.17	47	-5.64	16.36	39
	ALL	13.03	27.15	92	6.12	24.39	105	2.39	24.88	106
Toluene	1	-9.61	46.40	15	6.47	37.21	28	-0.73	43.95	34
	2	-15.23	56.56	16	-19.39	43.00	22	-0.16	43.62	30
	3	10.43	26.18	40	-3.40	26.18	46	-9.89	17.74	39
	ALL	1.58	40.72	73	-3.57	35.20	97	-2.95	36.36	106

[†] Units for mean and standard deviation (S.D.) are percent difference.

TABLE E-9. APPROXIMATE CONCENTRATIONS OF CALIBRATION CHECK SAMPLES ($\mu g/m^3$)

Compound	Level 1	Level 2	Level 3
Benzene	11	18	29
Carbon tetrachloride	7	12	20
Chlorobenzene	10	17	26
o-Chlorotoluene	9	18	27
1,2-Dibromoethane	8	13	19
o-Dichlorobenzene	9	18	27
1,1,2,2-Tetrachloroethylene	12	19	31
Toluene	11	19	28

TABLE E-10. SUMMARY OF RESULTS FOR POLYURETHANE FOAM CHECK SAMPLES[†]

		Check Sample Number					
Compound		1	2	3	4	5	6
1,2,3,4-Tetrachlorobenzene	Level	1,000 ng	1,500 ng	750 ng	3,000 ng	750 ng	900 ng
	Average	74.4	78.3	77.6	64.3	81.8	87.5
	SD	±14.1	±12.3	±25.6	±16.9	±15.8	±21.5
	% RSD	18.9%	15.7%	32.9%	26.2%	19.3%	24.5%
	N	11	11	10	8	16	12
Pentachlorobenzene	Level	400 ng	200 ng	100 ng	1,000 ng	500 ng	400 ng
	Average	77.3	86.3	83.3	69.7	85.1	86.4
	SD	± 9.9	±17.7	±26.7	±27.0	±18.2	±19.6
	% RSD	12.9%	20.5%	32.1%	38.8%	21.3%	22.7%
	N	11	11	10	9	16	11
Hexachlorobenzene	Level	600 ng	300 ng	150 ng	120 ng	200 ng	200 ng
	Average	99.2	116.2	104.2	91.1	94.9	84.3
	SD	±22.9	±42.8	±47.5	±31.2	±27.8	±22.7
	% RSD	23.1%	36.9%	45.6%	34.3%	29.2%	27.0%
	N	11	12	10	8	16	10
γ-BHC (Lindane)	Level	100 ng	150 ng	75 ng	200 ng	250 ng	250 ng
	Average	69.9	77.5	67.9	68.6	79.7	82.1
	SD	±23.0	±18.2	±48.8	±22.7	±20.0	±22.3
	% RSD	32.9%	23.5%	71.9%	33.2%	25.1%	27.2%
	N	11	11	10	9	16	11
2,4,5-Trichlorophenol	Level	300 ng	150 ng	75 ng	100 ng	1,000 ng	200 ng
	Average	75.1	89.6	90.4	68.4	77.1	86.2
	SD	±35.2	±53.8	±57.5	±38.0	±37.1	±16.4
	% RSD	46.9%	60.1%	63.6%	55.5%	48.1%	19.1%
	N	12	11	10	9	17	10

[†] Percent recovery ± SD, with percent relative standard deviation and number of samples

Table E-11. Analytical accuracy for NAA metals analyses was estimated from the results of NBS Standard Reference Materials. These results are presented in Table E-12.

Mean percent differences for all metals analyses were less than ±5 percent, except for zinc, which was -11 percent. No changes to the metals data were made based on these results. These results were judged consistent with the results obtained by EMSL-RTP, both prior and subsequent to the analysis of Love Canal samples.

TABLE E-11. RESULTS FROM THE ANALYSIS OF BLIND AUDIT SAMPLES BY ICAP

Element	Percent Difference Mean	Percent Difference S.D.	Number of Samples
Lead	-0.1	3.7	6
Nickel	-1.9	4.3	6
Zinc	-11.2	5.5	6

S.D.: Standard deviation

TABLE E-12. RESULTS FROM THE ANALYSIS OF NATIONAL BUREAU OF STANDARDS STANDARD REFERENCE MATERIALS BY NAA

Element	SRM 1648 Percent Difference Mean	SRM 1648 Percent Difference S.D.	SRM 1632 Percent Difference Mean	SRM 1632 Percent Difference S.D.	Number of Samples
Arsenic	4.7	10.1	-3.5	7.9	12
Cobalt	1.4	4.4	4.9	2.9	12
Chromium	-4.5	4.3	0.0	3.1	12

S.D.: Standard deviation
Note: For each SRM, 12 separate analyses were performed.

SUMMARY OF MAJOR ACTIONS TAKEN AS A RESULT OF THE GCA CORPORATION QUALITY ASSURANCE FUNTIONS

While most actions taken by EPA as a result of the quality assurance program occurred after analyses had been completed, the GCA Corporation quality assurance program was operative during the on-going measurement processes. One indication of the effectiveness of the GCA Corporation QA program was the fact that very few samples had to be invalidated retrospectively by EPA during its review of the data. To a great extent, the low number of invalidated samples were due to the adherence of the sampling and analytical subcontractors to the required quality assurance procedures. In addition, the GCA Corporation's management of the monitoring efforts, timely identification of potential problems, and initiating corrective actions before these problems became major resulted in analytical laboratories operating in control.

Some examples of the GCA Corporation quality assurance activities that eliminated minor problems before they adversely affected the data are as follows:

1. By reviewing the results of the calibration check samples (TENAX analyses) as they were reported, the GCA Corporation noticed that variability in one laboratory was approaching unacceptable limits. A site investigation by the GCA Corporation of the laboratory in question uncovered a minor leak in the injection system to their GC/MS. The leak was corrected, and variability of results on the calibration check samples decreased. No data needed to be invalidated because the problem was corrected while it was still minor.

2. The GCA Corporation monitored the TENAX tube clean-up dates at their Love Canal sample bank operation, and removed blank tubes which, in their estimation, could not be used to collect a sample and be analyzed within the prescribed 30-day time limit established at the start of the monitoring program. By this activity, the 30-day limit was adhered to throughout the study.

3. Once the TENAX collecting media was cleaned, a number of tubes from each batch were analyzed for background before the tubes were sent to the field. As a result, one complete batch of TENAX was rejected and removed from the study because of unacceptably high background analytical results.

Additional examples of the GCA Corporation on-going quality assurance activities are described in the Love Canal Monitoring Program, GCA QA/QC Summary Report.

REFERENCES

1. Pellizzari, E. D. Development of Analytical Techniques for Measuring Ambient Atmospheric Carcinogenic Vapors. Publication No. EPA-600/2-75-075, Contract No. 68-02-1228. November 1975. 187 pp.

2. ------------. The Measurement of Carcinogenic Vapors in Ambient Atmospheres. Publication No. EPA-600/7-77-055, Contract No. 68-02-1228. June 1977. 288 pp.

3. ------------. Evaluation of the Basic GC/MS Computer Analysis Technique for Pollutant Analysis. Final Report, EPA Contract No. 68-02-2998.

4. Pellizzari, E. D., and L. W. Little. Collection and Analysis of Purgeable Organics Emitted from Treatment Plants. Final Report, EPA Contract No. 68-03-2681. 216 pp.

5. Pellizzari, E. D. Analysis of Organic Air Pollutants by Gas Chromatography and Mass Spectroscopy. EPA-600/2-77-100. June 1977. 114 pp.

6. ------------. Analysis of Organic Air Pollutants by Gas Chromatography and Mass Spectroscopy. EPA-600/2-79-057. March 1979. 243 pp.

7. ------------. Ambient Air Carcinogenic Vapors Improved Sampling and Analytical Techniques and Field Studies. EPA-600/2-79-081. May 1979. 340 pp.

8. Lewis, R. G., A. R. Brown and M. D. Jackson. Evaluation of Polyurethane Foam for Sampling of Pesticides, Polychlorinated Biphenyls, and Polychlorinated Napthalenes in Ambient Air. Anal. Chem. 49. 1977. 1668-1672.

9. Lewis, R. G. "Sampling and Analysis of Airborne Pesticides", in Air Pollution from Pesticides and Agricultural Processes. R. E. Lee, Jr. (Ed.), CRC Press. 1976. pp. 52-94.

10. Lewis, R. G., K. E. MacLeod, and M. D. Jackson. Sampling Methodologies for Airborne Pesticides and Polychlorinated Biphenyl. Paper No. 65. Chemical Congress, ACS-Chemical Society of Japan, Honolulu, Hawaii, April 2-6, 1979.

11. Manual of Analytical Methods for the Analysis of Pesticides in Humans and Environmental Samples, Section 8. U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, North Carolina 27711, EPA-600/8-80-038. June 1980.

12. MacLeod, K. E. Sources of Emissions of PCBs into the Ambient Atmosphere and Indoor Air. U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, North Carolina 27711, EPA-600/4-78-022. March 1979.

13. Bidleman, T. F., J. R. Matthews, C. E. Olney and C. P. Rice. Separation of PCBs, Chlordane, and *pp*'-DDT from Toxaphene by Silicic Acid Column Chromatography. J. Assoc. Off. Anal. Chem., *61*:820-828.

14. Lewis, R. G., M. D. Jackson and K. E. MacLeod. Protocol for the Assessment of Human Exposure to Airborne Pesticides. U.S. Environmental Protection Agency, Health Effects Research Laboratory, Research Triangle Park, North Carolina, EPA-600/2-80-180. 1980.

APPENDIX F
REPORT ON THE AUDIT OF GAS CHROMATOGRAPHY/ MASS SPECTROMETRY DATA PROVIDED BY LOVE CANAL PROJECT ANALYTICAL LABORATORIES

INTRODUCTION

This report provides the results of an audit of raw gas chromatography/mass spectrometry (GC/MS) data archived on magnetic tape and provided by the Love Canal project analytical laboratories. It is emphasized that the audit was not applied to the complete analyses of samples by the contract laboratories, but only to the interpretation of raw GC/MS data as provided on magnetic tape.

The audit was accomplished by three EPA laboratories using Protocol for Auditing Gas Chromatography/Mass Spectrometry Data Provided by Love Canal Project Analytical Laboratories, revision 1.01 by W. L. Budde, E. H. Kerns, and J. W. Eichelberger, dated July 2, 1981. The participating EPA laboratories were the Environmental Monitoring and Support Laboratory, Cincinnati (EMSL-Cin), the Environmental Monitoring Systems Laboratory, Las Vegas (EMSL-LV), and the Environmental Research Laboratory, Athens (ERL-Athens).

SCORING SYSTEM--TARGET COMPOUNDS

In order to provide a quantitative measure of the performance of the laboratories, a scoring system was developed. This scoring system is based on two indices, the positive agreement index (PAI) and the negative agreement index (NAI), which are defined as follows:

$$\mathrm{PAI} = \frac{\mathrm{TP}}{\mathrm{T}} \times 100\%$$

$$\mathrm{NAI} = \frac{\mathrm{N - T}}{\mathrm{N - TP}} \times 100\%$$

where:

TP = the number of compounds on the method target compound list that were found by the analytical laboratory and confirmed to be present in the magnetic tape record of the analysis by the audit laboratory.

T = the total number of compounds on the method target compound list that were found by the analytical laboratory plus any additional target compounds that were found by the audit laboratory.

N = the number of method target compounds.

The PAI is a statement of the percentage of positive occurrences the two laboratories agreed upon; and, the NAI is a statement of how well the two laboratories agreed on what target compounds were not present above the method detection limit. The audit data used to compute the PAI and NAI values for the samples audited are shown in Tables F-1 and F-2 (laboratory abbreviations are explained in Table 4 of the text). For Method 624, the value of N was 39; for Method 625, the value of N was 68. The summary PAI and NAI values shown in Tables F-1 and F-2 were computed for each laboratory from the totals shown in the tables, and therefore represent the weighted means. The weighted NAI values were computed using a value of N weighted by the number of samples of each type (Method 624 or 625).

For most of the possible boundary conditions, the minimum and maximum values of the PAI and NAI indices are 0 and 100 percent. However, if no compounds are in the sample and both laboratories are in perfect agreement on this condition, the PAI is undefined, and the index has no meaning. If every single target analyte is present and both laboratories are in perfect agreement on this condition, the NAI is undefined and the index has no meaning.

To assist in interpreting the PAI and NAI scores, it was desirable to establish a reference point for performance. The EMSL-Cincinnati had acted as a referee quality assurance laboratory during the project, and analyzed 5 percent of the water samples and 3 percent of the soil and sediment samples (Tables F-3 and F-4). Data from three of the samples analyzed by EMSL-Cincinnati were audited by ERL-Athens to establish the level of agreement between two highly experienced laboratories that were also involved in the development of the methods and motivated to generate high quality scientific work (and work that was relatively free from the fixed price financial constraints that existed at the contract laboratories and which may have impinged on performance). The weighted mean PAI for these 3 samples was 71 percent and the weighted mean NAI was 94 percent. On this basis, TABLE F-1. SUMMARY OF EMSL-CINCINNATI AUDIT OF LOVE CANAL GC/MS WATER SAMPLES

Lab.	Method	Sample No.	T	TP	PAI	NAI
ACEE	624	W20877	3	1	33	95
	624	W20922	1	0	0	97
	624	W21732	2	1	50	97
	624	W25290	6	5	83	97
	624	W25506	7	5	71	94
	624	W25511	4	2	50	95
	624	W25628	4	2	50	95
	624	W25629	5	5	100	100
	624	W25654	3	3	100	100
	624	W25656	10	10	100	100
	625	W20872	1	1	100	100
	625	W21733	16	15	94	98
	625	W25507	0	0	undefined	100
	625	W25625	0	0	undefined	100
			62	50	81	98
PJBL	624	W20796	15	9	60	80
	624	W20825	3	3	100	100
	625	W20349	9	7	78	97
	625	W20808	24	11	46	77
	625	W20820	3	3	100	100
	625	W20856	0	0	undefined	100
			54	33	61	93
TRWW	624	W21976	10	8	80	94
	624	W22008	8	5	63	91
	624	W22009	15	9	60	80
	624	W22026	15	11	73	86
			48	33	69	88
CMTL	624	W21644	2	0	0	95
	624	W21663	0	0	undefined	100
	624	W21773	0	0	undefined	100
	625	W21774	0	0	undefined	100
	625	W21645	0	0	undefined	100
	625	W21818	0	0	undefined	100
	625	W25123	0	0	undefined	100
			2	0	0	99

(continued)

TABLE F-1 (continued)

Lab.	Method	Sample No.	T	TP	PAI	NAI
GSRI	625	W21516	1	0	0	99
	625	W21526	6	6	100	100
	625	W21537	0	0	undefined	100
	625	W25421	1	1	100	100
	625	W25432	0	0	undefined	100
	625	W25525	7	6	86	98
	625	W25564	0	0	undefined	100
			15	13	87	100
EMSL-Cin	625[†]	W21725	12	9	75	95
	625[†]	W25199	3	2	67	98
			15	11	73	97

[†] Audited by ERL-Athens

TABLE F-2. SUMMARY OF THE EMSL-LAS VEGAS AND ERL-ATHENS AUDIT OF LOVE CANAL SOIL AND SEDIMENT SAMPLES

Lab.	Method	Sample No.	T	TP	PAI	NAI
ACEE	624[†]	S50158	0	0	undefined	100
	624	S40085	4	3	75	97
	624	S40121	1	1	100	100
	624	S40576	4	2	50	95
	624	S40586	1	0	0	97
	624	S50150	5	2	40	92
	624	S50296	4	2	50	95
	625	S40087	0	0	undefined	100
	625	S40209	0	0	undefined	100
	625	S45206	13	10	77	95
			32	20	63	97
PJBL	624	S45526	5	4	80	97
	624	S45527	6	3	50	92
	624	S50257	7	4	57	91
	624	S50262	6	2	33	89
			24	13	54	92

(continued)

[†] Audited by ERL-Athens

TABLE F-2 (continued)

Lab.	Method	Sample No.	T	TP	PAI	NAI
CMTL	624	S45018	2	0	0	95
	624	S45027	2	0	0	95
	624	S45219	2	1	50	97
	624	S45398	3	0	0	92
	624	S50025	9	7	78	94
	624	S50031	5	2	40	92
	625	S45054	0	0	undefined	100
	625	S45119	10	5	50	92
	625	S50047	18	7	39	82
			51	22	43	93
GRSI	625	S40330	0	0	undefined	100
	625	S40332	0	0	undefined	100
	625	S40463	0	0	undefined	100
	625	S40464	6	3	50	95
	625	S40491	2	0	0	97
	624	S40414	0	0	undefined	100
	624	S40417	2	2	100	100
	624	S40425	1	1	100	100
	624	S40426	0	0	undefined	100
	624	S50238	3	3	100	100
	624	S50380	6	4	67	94
			20	13	65	99
SWRI	625	S40058	11	5	45	90
	625	S40178 (N25W15)	19	10	53	84
	625	S40178 (N25W16)	21	9	43	80
	625	S40796	13	10	77	95
	625	S40888	6	3	50	95
	625	S40908	15	9	60	90
	625	S50330	19	17	89	96
			104	63	61	90
EMSL-Cin	625[†]	S50068	20	14	70	89

[†] Audited by ERL-Athens

TABLE F-3. SUMMARY OF THE LOVE CANAL WATER DATA AUDIT

Analytical Laboratory	Samples Reported[†] (624 + 625)	Percent of Total	Number Audited by		Percent of Subcontractor Lab's Total Audited by	
			EMSL-Cin	ERL-Athens	EMSL-Cin	ERL-Athens
ACEE	214	28	14	--	6.5	--
CMTL	149	19	7	--	4.7	--
EMSL-Cin	38	5	--	2	--	5.3
ERCO	1	0	--	--	--	--
GSRI	159	21	7	--	4.4	--
ERL-Ada	8	1	--	--	--	--
PJBL	127	17	6	--	4.7	--
TRWW	69	9	4	--	5.8	--
Totals	765	100	38(5%)	2(0.26%)		

[†] In validated data base

TABLE F-4. SUMMARY OF THE LOVE CANAL SOIL AND SEDIMENT AUDIT

Analytical Laboratory	Samples Reported[†] (624 + 625)	Percent of Total	Number Audited by		Percent of Subcontractor Lab's Total Audited by	
			ERL-Athens	EMSL-LV	ERL-Athens	EMSL-LV
ACEE	150	21	1	9	0.7	6.0
CMTL	195	28		9		4.6
EMSL-Cin	24	3	1		4.2	
GSRI	141	20	6	5	4.3	3.5
PJBL	18	3		4		22.0
SWRI	174	25		7		4.0
Totals	702	100	8(1.1%)	34(4.8%)		

[†] In validated data base

it was judged not reasonable to expect a contract analytical laboratory to have any better agreement with an EPA audit laboratory than the two expert EPA laboratories had with each other. Consequently, it was assumed that reasonable, perhaps state-of-the-art, performance would be a PAI of 71 percent or better, and a NAI of 94 percent or better.

Throughout the audit, the results reported in the validated data base were compared with the audit laboratory's interpretation of the magnetic tape files. In some cases files from method blanks were available, and background from laboratory contaminants was subtracted before the scores were computed. In other cases, clearly corresponding files from method blanks could not be located and, while the analytical laboratory was given the benefit of the doubt on common laboratory contaminants, some additional uncertainty exists in the scores that needs to be considered when interpreting them. Therefore, a reasonable range of uncertainty may be ±10 percent for PAI and a reasonable acceptance range for PAI scores would be 61 to 81 percent. Missing method blank files and other uncertainties were judged to have much less impact on NAI scores and a reasonable acceptance range may be ±5 percent or a NAI score of 89 to 99 percent.

LABORATORY SCORES--TARGET COMPOUNDS

Tables F-3 and F-4 show the number of samples in the validated data base analyzed by each laboratory, the percent of the totals, the number audited, and the percent of each laboratory's total that was audited. Overall, 5.26 percent of the water samples and 5.9 percent of the soil and sediment samples were randomly selected from the validated data base and subsequently audited. At the beginning of the program, the target audit percentage was 5 percent, and deviations from this were caused by a number of factors including: (1) incorrect early estimates of the number of samples analyzed by each laboratory; (2) the failure to achieve distribution of all the magnetic tapes by the audit deadline; and (3) inability of the audit laboratories to read some tapes because of technical difficulties. In general, the intensity of the audit is believed to be acceptable and representative of the overall performance of contractor laboratories, that is, the conclusions would not change if double or triple the number of samples were audited. However, there were several exceptions where a reliable audit of contractor laboratory performance was not obtained. The laboratory CMTL was very slow in submitting data, and six of the seven water samples examined had no target compounds above the minimum detection limit. This resulted in nearly all audited samples having undefined PAI scores and the resulting audit was judged indeterminate. In similar fashion, the laboratory GSRI had three undefined water PAI scores which reduced the valid audited percentage to a very low 2.5 percent. On the other hand, the GSRI laboratory had five undefined PAI scores for soil and sediment samples, but the remaining six accounted for a reasonable 4.2 percent of the total soil and sediment samples analyzed by this laboratory.

Examination of Table F-1 reveals that all the weighted PAI means, except that of CMTL which was discussed previously, fall into the acceptance range of 61 to 81 percent or higher. Similarly, the NAI scores are all in the range of 89 to 99 percent except TRWW, which had an 88 percent. Only a few individual scores fell outside these reasonable acceptance ranges.

Among the laboratories analyzing soil and sediment samples, two laboratories (PJBL and CMTL) had below acceptable weighted mean PAI scores; all laboratories had weighted mean NAI scores in the acceptable range. The PJBL laboratory analyzed only 18, or 3 percent, of the total soil and sediment samples and was removed from the contract work early in the program for quality assurance reasons. The identification of potential QC problems associated with the performance of CMTL in soil and sediment analyses was substantially hampered by the late delivery of data to the prime contractor and EPA.

DISCUSSION--TARGET COMPOUNDS

The raw archived GC/MS data was studied carefully to assess those factors contributing to the generally less than perfect agreement on positive occurrences between contractor and EPA audit laboratories and between EPA laboratories. In general, it was found that the contributing factors reduced to differences in computer algorithms used by various laboratories to automatically detect peaks in total or partial ion chromatograms, and to distinguish real signals from chemical and other noise. Another major reason was found to be differences in judgment and identification criteria employed by various equipment operators and data interpreters. Although EPA methods do provide compound identification criteria, interpretations were found to differ at times, especially where there was little or no direct communication among interpreters at many sites. Different interpretations were especially noticed at concentrations below 30 parts per billion, which is the region of the method detection limit for many compounds. It was observed that some data interpreters were willing to accept mass spectra with some chemical noise (background) as valid proof for an identification, while other interpreters required relatively clean spectra before accepting an identification as correct.

A group of 18 water samples that contained 52 discrepancies in the findings of the analytical and audit laboratories was examined carefully to determine the effect of concentration levels. Of the 52 discrepancies, 49 occurred at concentrations below 30 micrograms per liter, which is well into the region of detection/quantitation limits for many of the laboratories. Of the 49 occurrences, 22 were reported as "trace" amounts. The remaining 3 discrepancies, which occurred above 30 parts per billion, may possibly be accounted for by missing method blanks. As was pointed out previously, clearly corresponding data files from method blanks could not always be located for the audit. Consequently, in some samples, compounds were found by the audit laboratory that were not reported by the analytical laboratory, and some of these may have been present in the method blank, which caused the analytical laboratory to delete the compound from the report. Furthermore, the conclusions of the study were based on levels of contamination that were orders of magnitude higher than the parts per billion levels that seemed to dominate the discrepancies between the analytical and audit laboratories. Therefore, the discrepancies in findings have little or no affect on the overall conclusions of the study.

NON-TARGET COMPOUNDS

The analytical laboratories were required by the terms of their subcontracts to attempt to identify up to 20 of the most abundant compounds in each sample that were not on the target compound list (non-target compounds). Table F-5 summarizes the results of the audit of this effort. In this table the information from water, soil, and sediment samples analyzed by both GC/MS methods was consolidated.

TABLE F-5. SUMMARY OF NON-TARGET COMPOUND AUDIT

Number of samples audited for non-targeted compounds (39 water, 41 soil and sediment)	80
Number of samples in which the analytical laboratories and the audit laboratories agreed that none were present	58(72.5%)
Total number of compounds identified by the analytical laboratories in the 22 remaining samples	1[†]
Total number of compounds identified by the audit laboratories in the 22 remaining samples	84[‡]

[†] Does not include 19 identifications reported by EMSL-Cincinnati as an analytical laboratory in 2 samples

[‡] Does not include 16 identifications reported by ERL-Athens as an audit laboratory for EMSL-Cincinnati as the analytical laboratory in 2 samples

As can be seen from the results presented in Table F-5, the audit and analytical laboratories agreed that no non-target compounds were present in nearly three-fourths of the samples reviewed. In most of the 22 samples containing non-target compounds the audit laboratory reported finding 1 or 2 compounds while the analytical laboratory reported none. There were 5 samples audited where 6 to 20 compounds were reported by the audit laboratory but none were reported by the analytical laboratory (CMTL and SWRI).

The results of the non-target compounds audit revealed that the estimated concentration levels of most omitted compounds was in the vicinity of the method limits of detection and quantitation. Furthermore, it was found that in those relatively few samples in which a discrepancy occurred in reporting non-target compounds, the audit and analytical laboratories agreed that the samples were already heavily contaminated with targeted compounds. Consequently, the results of the audit of non-target compounds was judged to not affect the general findings of the project.

CONCLUSION

Considering the extremely rapid start-up and completion of this project, which allowed very little time to develop the capabilities of the contract analytical laboratories, and the rapid response times required of the laboratories, the overall performance of contract laboratories was judged to be acceptable. In general, the overall findings of the project would not have been materially affected even if there had been perfect agreement between the analytical laboratories and the audit laboratories. This is because the great majority of discrepancies in the findings of the analytical and audit laboratories involved substances occurring at concentration levels in the vicinity of the method limits of detection and quantitation, and these discrepancies were nearly always restricted to samples that were correctly identified as being heavily contaminated with targeted compounds. The major conclusions of the monitoring study, however, were based on findings of environmental contamination at orders of magnitude higher concentration levels than the estimated concentrations levels comprising nearly all discrepancies.